Preventing Loss And Saving Lives

Earthquakes and Non-ductile Concrete Buildings in the City of Los Angeles

May 3, 2008

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ACKNOWLEDGMENTS

We want to thank Los Angeles Councilmember Greig Smith and Mark Benthien at the Southern California Earthquake Center for the opportunity to work on this important issue of earthquake hazard mitigation. Special thanks go to our advisor Dr. Juliet Musso, for her support and guidance throughout the project.

We express special appreciation to Dr. William Petak, an expert on seismic hazard reduction, who provided us with constructive feedback and contacts to key experts in the field.

COVER IMAGE - 1994 Northridge Damage to Kaiser Permanente Grenada Hills Office Building. From National Geophysical Data Center Natural Hazards Slides Sets. www.ngdc.noaa.gov

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EXECUTIVE SUMMARY

The impact of a major earthquake striking the City of Los Angeles will be substantial. Sophisticated models estimate that the economic losses could be as large as $252 billion, in addition to thousands of fatalities. While the City has made significant headway in improving building safety, non-ductile concrete buildings remain unaddressed. Retrofitting this vulnerable building stock is critical in reducing earthquake damage, yet it is costly and private property owners often lack incentives to take action. The Southern California Earthquake Center and City of Los Angeles Councilman Greig Smith have partnered to sponsor this study of potential policies to reduce earthquake hazards by encouraging the retrofitting of non-ductile concrete structures.

Non-ductile concrete structures present particularly high risks to occupants as they are dangerous and difficult to identify. Generally built before 1976, these buildings have stiff reinforced concrete frames that do not bend when shaken or twisted, which increases the likelihood of structural failure. Non-ductile concrete buildings are virtually unidentifiable from the outside. They look similar to reinforced concrete frame buildings constructed to higher seismic safety standards, and their facades bear likenesses to other building types. To determine a building's vulnerability and required retrofits, engineers would have to consult architectural diagrams or conduct structural assessments. There is no current tally of the number of these buildings in the city, with estimates ranging from 500 to 3,000.

The City of Los Angeles has traditionally been a world leader in earthquake building safety policy. Such policies reduce the risk of any number of consequences, whether economic loss and business interruption, or injuries and the loss of life. Due to the shortcomings of private risk reduction strategies, government intervention continues to play a valuable role.

This project analyzed two policy options:

1. Local government legislation mandating retrofitting of non-ductile concrete structures.
2. Local government legislation establishing a program in which building owners disclose their non-ductile concrete structure's risk using publicly posted signs or placards. This project considers both a voluntary and a mandatory placard program.

To compare these policies, the project team employed a five step process: 1) Development of Information, which included defining concepts and obtaining data; 2) Selection of Criteria, by which the results would be compared; 3) Construction of Theoretical Models, to map outcomes; 4) Simulation of the Policies' Impacts, by entering the information and data into the models; and, 5) Comparison of the Policies' Impacts, by the chosen criteria through quantitative and qualitative analysis.

Results and Recommendations

The results of the analysis show that City of Los Angeles should develop a policy to increase the number of non-ductile concrete buildings that are retrofitted. A policy mandating the retrofitting of privately owned buildings would likely provide the greatest gains to society, with risk-adjusted overall economic benefits of $56.4 million, and the avoidance of 5 deaths and 56 injuries. A policy requiring the posting of seismic warning placards on seismically risky non-ductile concrete buildings would likely achieve overall economic benefits to the city of $10.7 million, save 1 life and prevent 11 injuries. Although several other types of placard policies were considered, they were determined to be largely ineffective. Both selected policies are likely to be constrained by political resistance and implementation barriers, given the current city budget deficit and the uncertain economic environment. Therefore, we propose a number of cost-saving recommendations:

- If implementing a mandate, adopt a flexible and feasible time frame for implementation.
- Agree upon a clear definition of non-ductile concrete buildings including identifying characteristics, distinct structural categories, vulnerable types, and common structural vulnerabilities.
- Develop an inventory of non-ductile concrete buildings within the City of Los Angeles.
- Identify those non-ductile concrete buildings which are most vulnerable, including assessments of building usage (social function) to identify human and economic costs of structural failure and include only those in the policy.

There is a careful balance between having an adequate amount of time to develop a well reasoned and implementable policy, and ensuring that the process takes place. We recommend that policy makers:

- Expect the process of creating a new policy to take time as stakeholders are educated and definitions are reached.
- Yet continue to move forward despite information gaps.

Finally, we urge policy makers to avoid waiting for a major earthquake to happen before adopting a policy. To be effective, the process to save lives and prevent loss should begin as soon as possible.

1 INTRODUCTION

The impact of a major earthquake striking the City of Los Angeles would be substantial. Sophisticated models estimate property damages would be greater than $47 billion, in addition to a large number of fatalities. While significant headway has been made in improving building safety, non-ductile concrete buildings remain unaddressed. Retrofitting of the existing building stock is critical in reducing earthquake damage, yet retrofitting is costly and private property owners often lack incentives to take action.

Figure 1-1. 1971 San Fernando Earthquake, Olive Valley Hospital, was once two stories. Source: World Housing Encyclopedia. http://www.world-housing.net/uploads/101108_111_10.jpg

1.1 Scope of Project

This project considers the possibility of government intervention to reduce the risk posed by non-ductile concrete buildings in the City of Los Angeles. Although many building types pose seismic risk, this project is limited to the type often referred to as non-ductile concrete structures. These buildings have frames made of reinforced concrete, were generally built prior to 1976, and can be brittle and prone to break. Building attributes such as weak first stories can compound the danger presented by these structures. A more comprehensive explanation of these buildings is provided in Section 2.2, Structural Failure During Earthquakes.

Government intervention to encourage, or mandate the retrofit of privately owned structures can be complicated and costly. The project team was asked to explore and evaluate two potential policy options:

1. Local government legislation mandating retrofitting of non-ductile concrete structures.
2. Local government legislation establishing a program in which building owners disclose their non-ductile concrete structure's risk using publicly posted signs or placards. This project considers both a voluntary and a mandatory placard program.

This purpose of this project is to inform the decision making of the City of Los Angeles regarding the seismic retrofitting of non-ductile concrete buildings. The policies are evaluated and compared using qualitative and quantitative means, specifically the criteria of economic efficiency, human safety, political feasibility, and implementation opportunities and constraints.

1.2 Overview of Report

This report is the conclusion of a year-long effort by three second-year Master's of Public Policy candidates at the University of Southern California's (USC) School of Policy, Planning and

Development. The project was conducted for the Southern California Earthquake Center (SCEC) and City of Los Angeles Councilman Greig Smith, under the guidelines set out by the Master's of Public Policy program.

Section 1 provides an overview of the scope, purpose and background of the project. **Section 2** explains the danger that a major earthquake poses to the City of Los Angeles and tackles the issue of non-ductile concrete buildings. The discussion of the buildings includes what they are, why they fail, how they are retrofitted and how many of the structures exist in the city. **Section 3** provides the platform for adoption of new legislation through an exploration of the history of seismic legislation in the city and state. **Section 4** presents the proposed policy options and their variants. **Section 5** outlines the methodology used to conduct the analysis of the policies. The details of the data collection, cost-benefit analysis, building owner decision sub-model and application of evaluative criteria are provided in Appendix C of the report. **Section 6** presents the results of the analysis. **Section 7** provides recommendations for council action.

2 THE VULNERABILITY OF THE CITY AND ITS NON-DUCTILE CONCRETE BUILDINGS

The City of Los Angeles is vulnerable to damage caused by earthquakes whether the epicenter is within or beyond the region.[1] There is a 67 percent probability that a large earthquake (6.7 magnitude or greater) will occur in the Los Angeles region by 2038.[2] Resulting casualties, fatalities, loss of property value, opportunity costs, and cleanup costs would at least equal the impact of California's last major seismic event, the 6.7 magnitude 1994 Northridge earthquake. As a result of Northridge, fifty-seven people were killed, nearly 9,000 people were injured and the Los Angeles region suffered over $47 billion in economic damages.[3] Although both local and state legislation have required that newly built structures be able to withstand shaking, and some classes of older buildings be retrofitted, many residential and commercial structures remain extremely vulnerable to a seismic event.[4] Non-ductile concrete structures present particularly high risks to occupants. In the City of Los Angeles, these structures were generally built prior to 1976,[5] and have stiff frames that do not bend when shaken or twisted, resulting in structural failure during major earthquakes.[6]

The City of Los Angeles remains vulnerable to earthquake hazards despite having some of the most forward thinking seismic policy making in the world. This section addresses the two critical reasons. First, the Los Angeles region is littered with fault lines. Second, "earthquakes don't kill people, buildings do." Vulnerabilities in existing structures, such as non-ductile concrete structures, carry the risk of causing death, injury, and economic loss. Section 2.1 presents data from Los Angeles and beyond to provide an idea of the overall impact a major earthquake may have. Section 2.2 explains why structures, and specifically non-ductile concrete buildings, fail. Section 2.3 discusses seismic retrofit strategies for non-ductile concrete structures which reduce the risk of structural failure, human injury and death, and economic loss.

2.1 Future Earthquakes Impacting the City of Los Angeles

It is well known that an earthquake will impact the City of Los Angeles again. A complex network of fault lines runs under the Los Angeles region. Moreover, due to the composition of the region, the City of Los Angeles is vulnerable to seismic waves generated by the San Andreas

[1] United States Geological Survey (USGS), *Land and People: Los Angeles the Geologic Hazards of La Crescenta*, (2007) http://interactive2.usgs.gov/learningweb/textonly/students/landpeople_s_la_hazards.htm (accessed September 13, 2007).

[2] Edward H. Field, et al, *The Uniform California Earthquake Rupture Forecast, Version 2* (United States Geological Survey, 2008).

[3] California Seismic Safety Commission (CSSC), *Northridge Earthquake Turning Loss to Gain*, (CSSC, 1995) Report No. 95-01. http://www.seismic.ca.gov/pub/cssc95-01/cssc5-01b-toc.pdf (accessed September 13, 2007).

[4] CSSC, *Progress Report for the California Earthquake Loss Reduction Plan 2002-2006*, (CSSC, 2003), http://www.seismic.ca.gov/pub/cssc95-01/cssc5-01b-toc.pdf (accessed September 13, 2007).

[5] The City of Los Angeles building code was amended to enforce ductility in newly built concrete frame structures in 1973, however, they may have continued to be built until 1976.

[6] Earthquake Engineering Research Institute (EERI), *EERI Announces Concrete Coalition: Major Initiative Aims to Find and Fix Earthquake Dangerous Buildings*, http://peer.berkeley.edu/grandchallenge/news.html (accessed October 4, 2007)

Fault. Seismologists are not able to predict when, where, or with what magnitude the next earthquake will occur. The 1994 Northridge Earthquake occurred on a previously unknown fault line. Instead, seismologists provide estimations about the likelihood of an earthquake with a given magnitude striking during a certain time period.

Recent geologic studies have revealed a dangerous fault system, the Puente Hills blind thrust, buried directly beneath Los Angeles, California.[7] Should a catastrophic seismic event along the Puente Hills blind thrust occur, it would cause an estimated economic loss between $82 and $252 billion dollars. It would also create between 3,000-18,000 fatalities, 142,000-735,000 displaced households, 42,000-211,000 people in need of short-term public shelter, and will generate 30,000-90,000 tons of debris.[8] Although likelihood of a Puente Hills rupture is rare, with an estimated occurrence of once every 3,000 years, it is illustrative of the damage which could be caused by just one of many known fault lines which runs through the Los Angeles region.

Another illustrative example is that of the 1995 Kobe (Japan) Earthquake, which measured 7.3 on the Richter scale. Its epicenter was located directly beneath a metropolitan area magnifying its impact. Over 5,500 persons were killed, 67,421 structures were fully collapsed and 55,145 structures were partially collapsed.[9] Many of these structures were reinforced concrete buildings which collapsed due to the failure of their columns.[10] As this occurred in an advanced industrial country that has similar seismic standards to California, it provides evidence that Los Angeles is not, by virtue of the building code, immune to major loss of life and damages caused by an earthquake.

2.2 Structure Failure during Earthquakes

While many building types are likely to be affected during a major earthquake, non-ductile concrete structures are among the most vulnerable. To understand why, we first address why buildings fail during earthquakes in general. Second, we endeavor to define the broad category of non-ductile concrete structures and categorize specific design and structural component risks within those categories. Finally, we look at practices to retrofit these high-risk buildings.

Clarifying Terms

Seismic Resistance *– A structure's ability to withstand the motion caused by shaking.*

Failure *– When a structure suffers significant damage as the result of shaking.*

[7] Shaw, J., & Shearer, P. "An Elusive Blind-Thrust Fault Beneath Metropolitan Los Angeles" *Science* 283(5407) (1999, March): 1516.

[8] Edward H. Field et al, "Loss Estimates for Puente Hills Blind-Thrust Earthquake in Los Angeles, California," *Earthquake Spectra,* 21(2) (2005, May): 329.

[9] The City of Kobe, Japan. *The Great Hanshin-Awaji Earthquake Statistics and Restoration Progress*, (January 1, 2008) http://www.city.kobe.jp/cityoffice/06/013/report/index-e.html (accessed on April 8, 2008): 3.

[10] Otani, Shunsuke. "Earthquake Resistant Design of Reinforced Concrete Buildings Past and Future," *Journal of Advanced Concrete Technology*. 2(1) (February 2004): 20.

2.2.1 Failure Due to Forces

The failure of buildings from shaking is rarely due to a single joint or design element. As the ground moves, objects on the ground have force put upon them and move also. The frequency, direction and force of the movement, combined with the soil type and structure of a given building all contribute to the resilience or vulnerability of a building during an earthquake. The ways that earthquake generated forces impact an individual building are critical to understanding of why that building demonstrated seismic resistance or failed. Most importantly, the relationship of the ground shaking to the amount of force applied to the components of an individual building may not be linear, the building's attributes and components can increase the forces.

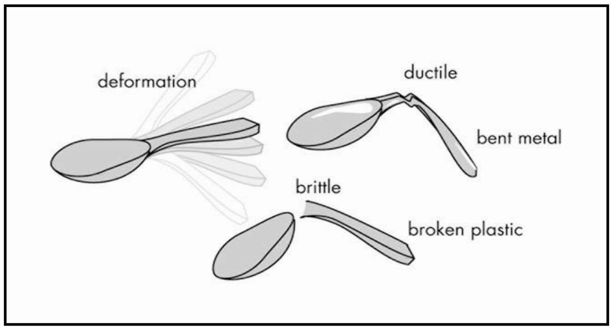

Figure 2-2. Demonstration of Ductility [11]

Buildings have a certain amount of ability to withstand these forces, resulting from the combination of ductility, stiffness, strength, force distribution and stress concentration. Equally, structural failure can be caused by a lack of these factors. Buildings can fail when they are not strong enough to carry the increased stress created during an earthquake. Moreover, either uneven strength distribution or stress concentration, within the structure can cause the building to give. For example, if weight is not evenly distributed, it may rotate around an unstable point resulting in torsion and hence structural failure. Buildings also fail due to insufficient ductility; they lack the ability to flex and recover during the motion of an earthquake. The diagram in Figure 2-1 shows how a metal spoon bends and reshapes more easily than a brittle plastic spoon, which would break under movement.[11] A related source of breaking is the uneven distribution of structural stiffness. The force placed upon the building during an earthquake is distributed across it in relation to its stiffness. If one building component is stiffer, it may take a load of the force which it is unable to carry, resulting in collapse.

Certain components of buildings tend to bear a great deal of the force and load resulting from earthquakes. For our purposes, the key components are: frames (consisting of columns and beams); slabs; walls; and, foundations. The point where two or more components intersect and are connected is a joint. The diagram to the left, Figure 2-2, shows these components.

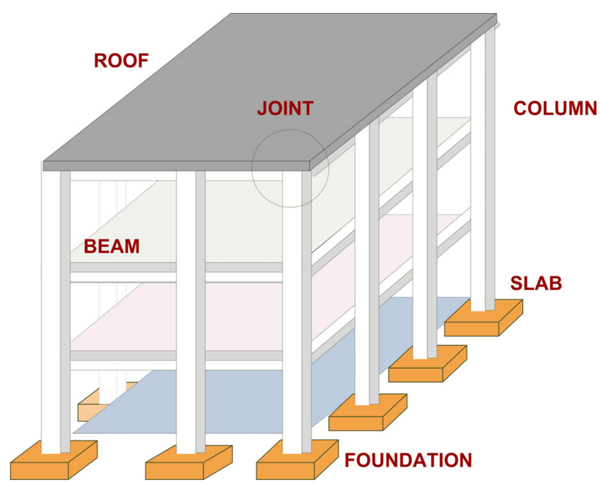

Figure 2-1. Diagram of Key Building Components

[11] Federal Emergency Management Agency (FEMA), *Designing for Earthquakes: A Manual for Architects; Providing Protection to People and Buildings* (FEMA 454, Risk Management Series, December 2006): 110.

Building columns, walls and joints are often referred to as either "load bearing" or "non-load bearing" indicating that they are, respectively, either essential to the structure or, could be removed with minimal impact. Seismically stable buildings often have one or more walls known as a "shear wall". A shear wall is a load bearing wall which is designed specifically to withstand shifting loads, such as those which occur during earthquakes.

2.2.2 Defining Non-ductile Concrete Buildings for Los Angeles

Figure 2-3. Non-Ductile Concrete Structure (FEMA 154, p.29) May look similar to ductile concrete and steel frame buildings.

The term "non-ductile concrete structures" can be applied to a broad range of structures, including buildings and bridges which exist all over the world. At the most basic level, it implies that a structure's frame is made of reinforced concrete and is brittle. Although a world-wide problem, a global understanding of these structures is of minimal usefulness to this project as the State of California has much higher seismic standards than the most of the rest of the world. This project specifically addresses those buildings in the City of Los Angeles which are non-ductile concrete structures.

Although there are multiple definitions for these buildings and explanations of why they fail, this project endeavors to provide a comprehensive overview of these buildings that applies specifically to the City of Los Angeles. The identification of non-ductile concrete buildings is made more difficult by their appearance. They are virtually unidentifiable from the outside as they look very similar to reinforced concrete frame buildings constructed after seismic standards were put into place, and, their facades can be quite similar to steel frame buildings. In interviewing experts, including policy makers and engineers, many answers mirrored Supreme Court Justice White's famous statement on obscenity; they "would know it if they saw it." Engineers would ideally consult architectural diagrams or conduct structural assessments to determine these buildings' frame composition and innate seismic resistance.

As stated above, non-ductile implies the absence of the important property of ductility of the frame of the building. Ductility is incorporated into post-1976 construction through the use of special reinforcing steel within the reinforced concrete beams and columns. This steel, when used properly, provides additional elasticity to the concrete, allowing it to retain its strength during seismic activity.[12] In much simplified terms, concrete is a fairly brittle material. Adding ductility to it allows the column or beam to bend in response to seismic waves without breaking or separating.[13]

[12] FEMA, *Designing for Earthquakes: A Manual for Architects; Providing Protection to People and Buildings* (FEMA 454, Risk Management Series, December 2006): 111.

[13] FEMA, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook,* (FEMA 154, 2002): 112-116.

Non-ductile concrete structures generally fail because they are brittle, and lack flexibility. Much like the plastic spoon in the above example, the seismic waves cause the structure to move. There are many possible causes and sources of failure, although some are more dramatic and some are more likely to be deadly than others. Other sources of failure include variable stiffness of concrete components and breakage of linkages at joints. There are also certain building types which can make an already risky concrete-frame building even more unsafe. Concrete frame buildings may also have reinforced concrete shear walls and unreinforced masonry (URM) infill walls. Additionally, any of these buildings may have a configuration causing a soft-story effect or building torsion.[14] A list of building types and attributes which fit into this category is provided at the end of this section as Table 2-1.

Figure 2-4. 1971 San Fernando Earthquake, Olive Valley Hospital NDCB Column Source: World Housing Encyclopedia. http://www.world-housing.net/

2.3 The Number of Non-ductile Concrete Buildings in the City

There is not a current tally of the number of non-ductile concrete structures according to any definition for the City of Los Angeles. This project utilizes several sources, which place the total number of such buildings as being between 500 and 3,000. In counting only privately owned buildings the baseline estimate is that there are approximately 2,000 of these buildings within the city. [15] However, based on the attributes listed above, it is expected that only a small portion (5-10 percent) of those buildings will present a particularly high risk to occupants. [16] A detailed explanation of the number of buildings and sources of information is provided in Appendix A, Number of Non-Ductile Concrete Buildings in the City.

These numbers will be further refined over time by various groups. The Concrete Coalition, as stated on its website, is “a joint project of Earthquake Engineering Research Institute (EERI), Pacific Earthquake Engineering Research (PEER) Center and the Applied Technology Council (ATC) to identify and reduce the earthquake risks posed by older non-ductile concrete buildings” is bringing together experts to study the problem on a local and global basis. Additionally, PEER, and the National Network for Earthquake Engineering Simulation

[14] FEMA, *Designing for Earthquakes: A Manual for Architects; Providing Protection to People and Buildings* (FEMA 454, Risk Management Series, December 2006): 111.

[15] Nick Delli Quadri, Los Angeles Department of Building and Safety, interviewed by the authors, April 13, 2008.

[16] Craig Comartin, EERI and Concrete Coalition, interviewed by the authors on March 18, 2008.

received a 5-year, $3.6 million National Science Foundation Grand Challenge Grant in late 2006. The project includes a wide network of experts and universities and intends to make an estimate of the number of non-ductile concrete buildings in the city.[17]

2.4 Retrofit Strategies for Non-ductile Concrete Buildings

The appropriate retrofit for particular a building will depend on the structure of the building, its components and configuration. There is not a one-size fits all solution. Generally, retrofitting involves adding new, enhancing existing and/or improving connections between elements, reducing the forces (demand) on the building or even removing selected components.[18] The elements added may be shear walls, columns or beams of concrete or steel, balancing walls, new frames, chords or even floor area. This can prevent building failure by providing a backup source of strength, a replacement of the existing source of strength or prevent the building from moving in a way that causes weakness or torsion. Existing elements may be enhanced by increasing the size of beams or columns, wrapping selected columns with a fiber composite or concrete/steel jacket, improving weak joints, and even uncoupling non-load bearing walls to prevent torsion. This modification can add ductility and may prevent failure due to weak joints. Reducing demand and removing selected components can involve: removing upper stories or seismically isolating, providing supplemental damping for, and/or removing those components which are creating short columns.[19] An overview of common retrofit techniques is included in Table 2-1.

Where possible, firms doing seismic rehabilitation attempt to limit the disruption caused to the building occupants. As such, seismic rehabilitation is often completed by adding exterior elements. For further explanation of these buildings, a good reference may be *Techniques for the Seismic Rehabilitation of Existing Buildings: FEMA 547*, available online at www.fema.gov. An explanation of the costs of retrofitting and how the costs were projected for this project is included as Appendix A, Non-Ductile Concrete Buildings in the City.

[17] Mary Comerio, Pacific Earthquake Engineering Research Center and UC Berkeley, and Thalia Anagnos, EERI and San Jose State University, interviewed by the authors February, 22 2008.
[18] FEMA, *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA 547, 2007): 12-4.
[19] FEMA, *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA 547, 2007): 12-5

Table 2-1. Characteristics of Non-ductile Concrete Buildings

Characteristic	General Information	Reasons for Structural Failure[20]	Common Retrofit Techniques[21]
Non-ductile Reinforced Concrete Frame	Various types of concrete frames exist. They may fail structurally for any of the reasons shown at right.	• Excessive tie spacing in columns • Placement of/inadequate rebar in columns • Insufficient column strength • Insufficient anchorage • Lack of continuous beam reinforcement • Inadequate joint reinforcement	• Add shear walls, steel bracing, new concrete or steel frame • Increase size of beams and/or columns • Fiber composite wrap around or steel/concrete jacket of critical columns • Remove upper stories • Perform improvements to joints
• With reinforced concrete shear wall	A shear wall should provide strength, however, NDCS with shear walls may be too heavy and/or stiff, resulting in the shear wall breaking away from the structure.	• Severe shaking can cause cracking in walls and beams • Failure at wall joints at high loads • May also fail due to bending	• Any of the items above • Apply additional layer to wall • Fill existing building openings (windows/ doorways) with concrete • Reinforce by adding elements to building boundaries
• With unreinforced masonry infill walls	Exterior walls between the frame and possibly interior walls are made of unreinforced masonry. Generally built before 1940.[22]	• Shaking causes infill walls to fail and effectively disintegrate • Falling hazard from bricks and collapse hazard from failure	• Any of the items above • Anchor components and tie downs • Add interior concrete walls • Add interior steel braced frames • Infill selected openings
• With "soft-story" type attributes (could be found in any of the above).	Ground or foundation story has attributes which make it weaker than rest of building. Warrants separate consideration as these buildings may pose the highest risk.	• Taller first story causes difference in stiffness between stories • Open first floor (i.e. parking garage) and heavy levels above excessively weight first story • First two stories different strengths causing deformations[23]	• Any of the items above • Add wall or adequate columns beneath • Add strength or stiffness in soft story to make floors "balance"

[20] FEMA, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook,* (FEMA 154, 2002): 112-116.
[21] FEMA, *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA 547, 2007): 12-4; 13-5; 15-5.
[22] FEMA, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook,* (FEMA 154, 2002): 30.
[23] Ahmet Yakut *Reinforced Concrete Frame Construction. World Housing Encyclopedia*, http://www.concretecoalition.org/links.php (accessed on January 17, 2008.)

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3 LEGISLATING SEISMIC SAFETY

Collective measures to reduce seismic risk are essential for those living in the City of Los Angeles. For over a century, citizens and policy makers across the region have been taking steps to reduce the human and economic costs of earthquakes. This section discusses the role of government in seismic safety. First, the case for government intervention is provided, by presenting the shortcomings of private risk reduction efforts. Second, selected past and present policies affecting the City of Los Angeles are documented. An understanding of the history and impacts of seismic policy is important to this project, as past experience provides the foundation for many future projections made in this project.

3.1 The Case for Government Intervention

The typical goal of earthquake related policy is risk reduction. This can mean reducing the risk of any number of consequences, whether economic loss and business interruption, or injuries and the loss of life. Although owners and users of non-ductile concrete structures can exercise a number of strategies to reduce risk, these strategies are imperfect, creating spaces for government policy to intervene and play a valuable role.

Earthquake risk can be reduced through a number of strategies. Individuals may purchase or rent property in areas less affected by earthquakes, invest in or occupy property that is built to withstand earthquake damage, or diversify their property portfolios. Post-investment actions include retrofitting property, preparing an emergency stockpile, or planning an escape route. However, any strategy relies on information about future events. And despite impressive advances, earthquake prediction remains imprecise.[24]

> ***Clarifying Terms***
>
> ***Information Asymmetry:*** *Occurs when one party has more or better information than another party in a transaction. A lack of information regarding earthquake risk leads to distortion in the insurance market.*
>
> ***Moral Hazard:*** *Occurs when protection from harm causes riskier behavior. Insuring buildings against earthquake damage reduces economic loss, yet does not protect the occupants.*
>
> ***Bounded rationality:*** *Occurs when individuals make decisions that do not maximize their utility, because of a lack of information or miscalculation of risks.*

The market solution to risk is the offering of insurance (risk pooling, in which speculators seek profit in the market through pooling customer risk, and customers pay into a common pot that can be accessed in a time of misfortune).[25] However, the market can fail, requiring government intervention. As economist Kenneth Arrow first pointed out, when information asymmetry remains, some events are too risky to insure. For example, the 1994 Northridge earthquake occurred on a previously unknown fault line. Insurance brokers raised premiums to meet greater than expected payouts and many residential consumers were priced out of the market. The State of California intervened, creating the California Earthquake Authority in September 1996, which

[24] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (Oregon State University Press, 2001).

[25] Kenneth J. Arrow, "Uncertainty and the Welfare Economics of Medical Care," *American Economic Review* 53 (1963).

enables homeowners to insure themselves against earthquake risk.[26] This "hidden action" problem creates a "moral hazard," whereby individuals may behave in a riskier fashion when insured. For example, owners of these buildings might insure their property instead of investing in risk mitigation. This reduces economic risk, but does nothing to improve safety for building users.

Another related problem is that individuals have difficulty judging risk accurately, due to both dynamic risk perception and bounded rationality. In dynamic risk perception individuals incorrectly perceive risk as declining as their memory of the event fades. Risk perception studies show that this effect can be explained by the fact that decision making is often emotional rather than calculated when considering "extreme" (low probability, high cost) events.[27] In 2005 the California Seismic Safety Commission (CSSC) estimated that "only 11 percent of all commercial property owners in California were insured for earthquakes..."[28] Although we do not have access to commercial insurance data, the actions of homeowners illustrate this problem. Since the 1994 Northridge earthquake, there has been a declining demand for California state homeowners insurance. In 2001 for example there were 900,000 policyholders, while in 2007 there were only 755,000 policyholders.[29] It is expected that owners and users of non-ductile concrete buildings are less likely to invest in earthquake risk reduction than they are immediately following an earthquake, when it is too late. In bounded rationality, individuals making decisions do a poor job of estimating risk when faced with uncertainty. Such risk perception phenomena are discussed further in Section 5.2.1, Decision Modeling for Business Owners and Users.

In sum, choices not to retrofit non-ductile concrete structures may be influenced by information asymmetry, the moral hazard of insurance, the presence of dynamic risk perception and bounded rationality. An opportunity for government intervention is presented by these spaces, as risk reduction is encouraged by information symmetry (placards would help achieve this), and ensured by retrofit mandates.

3.2 Government Efforts to Ensure Earthquake Safety

As noted above, the primary goal of earthquake related policy is to reduce risk. Since the early 1900's, a large number of policies designed to reduce earthquake related risk have been proposed and adopted at the local, state and national levels. Although the Federal government plays a role in broader earthquake policy, most seismic policies are made at the local and state levels, and structure-related policies are generally found in municipal building codes. In fact, Southern California has acted as an "incubator" of sorts for seismic policy and has produced the most far-reaching policies in the world.[30]

[26] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 265.
[27] Burns, W.J. (2007) Risk Perception: A Review, CREATE (USC) report.
[28] California Seismic Safety Commission (CSSC). *Commercial Property Owner's Guide to Earthquake Safety*, Report No. 06-02. (CSSC, 2006): 5.
[29] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 265.
[30] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 329-347; Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001): 5.

3.2.1 Municipal Building Codes

Municipal building codes are the heart of seismic retrofitting policy in Los Angeles and California. Building codes are the rules affecting all construction activity within jurisdictions. In terms of earthquake hazard mitigation, they require that all new residential and commercial structures are built to resist ground shaking, within certain limits. Alongside specific municipal requirements, certain types of critical public service buildings, such as schools, hospitals, and fire stations, are required by state law to be more resistant to structural failure. However, the majority of building codes are not retroactive. In fact, many seismic retrofit policies are voluntary or only triggered when major structural renovation is planned.[31] This results in a wide gap between building codes for new construction and those for existing buildings.

3.2.1.1 The Current Status of City of Los Angeles's Building Codes

In the City of Los Angeles, building codes appear in Chapter IX of the Municipal Code, and are administered by the Department of Building and Safety. The city first incorporated seismic considerations into the building code in 1933, in response to the Long Beach earthquake.

> ***Clarifying Terms***
>
> *Unreinforced Masonry (URM) and Reinforced Concrete*
>
> *Readers may be familiar with the use of the term "Unreinforced Masonry", often used to refer to a class of brick buildings which are exceptionally vulnerable to shaking.*
>
> *Here the term "reinforced" refers to the presence of some type of reinforcing material, such as steel rods, in the concrete, regardless of the amount of seismic resistance that the material provides.*

The current building code regulates a broad range of structural elements to improve earthquake hazard safety, such as exterior wall coverings (code 91.14), roofs (code 91.15), structural forces (code 91.16), foundations and retaining wall (code 91.18), and concrete (code 91.19). Numerous other regulations govern aspects such as materials, elevators, and construction rules. However, the gap between the building code for new construction and retrofitting is clear. Earthquake hazard reduction mandates for existing buildings only apply to URM buildings built prior to 1934 regulations (code 91.88) and tilt-up concrete wall buildings built prior to 1976 (code 91.91). A further five sections of the code provide voluntary "minimum standards" for certain types of existing buildings. These structures caused uncommon loss of life, injury, and damage during the 1994 Northridge Earthquake and include residential buildings with wood frames, weak walls, hillside buildings, and reinforced concrete and reinforced masonry wall buildings with flexible diaphragms. Critically for this project, code 91.95 lays the groundwork for a future ordinance by providing voluntary minimum standards for non-ductile concrete buildings:

> *The purpose…is to promote public safety and welfare by reducing the risk of death or injury that may result from the effects of earthquakes on [non-ductile] concrete buildings and [non-ductile] concrete frame buildings with masonry infills. The Northridge Earthquake caused widespread damage to these buildings, including some collapses. The recent Great Hanshin Earthquake in Kobe, Japan also caused collapse or partial*

[31] For more discussion of "trigger" earthquake building codes, please refer to Cynthia A. Hoover, *Seismic retrofit policies: An evaluation of local practices in zone 4 and their application to zone 3*, (DIANE, 1992).

> *collapse to several hundred of these buildings. These non-ductile concrete buildings are frequently used in Los Angeles for department stores, office buildings, hotels, parking structures and apartment houses. The performance of these structures in an earthquake is essential to the life-safety of their occupants and to significantly reduce the amount of building damage. This division provides voluntary retrofit standards that, when fully followed, will substantially improve the seismic performance of these buildings but will not necessarily prevent all earthquake damage.[32] …The provisions of this division may be applied to all buildings designed under building codes in effect prior to January 13, 1976, or built with building permits issued prior to January 13, 1977, having concrete floors and/or concrete roofs supported by reinforced concrete walls or concrete frames and columns, and/or concrete frames with masonry infills.[33]*

In early 2007, Los Angeles Councilmen Greig Smith introduced two earthquake-related pieces of legislation. The first is a motion calling for the identification and inventory of non-ductile concrete and tuck-under buildings (Council File Number (CFI) 04-0092).[34] The second motion required public disclosure of the seismic standard of every building (CFI 07-0144).[35] Both motions have been sent to the Building and Safety Committee for review, but have not proceeded. Interestingly, there have been no major changes to the seismic hazard mitigation policy elements of the building code in over ten years.

3.2.2 The History of Earthquake Legislation Affecting Los Angeles

Seismic safety policy began to be discussed in California after the 1906 San Francisco Earthquake. Numerous works recount the detailed and fascinating history of California's earthquake policy over the past century, and the important role Los Angeles has played in this story.[36] An understanding of the history and impacts of seismic policy is important, as past experience forms the basis for many future projections made in this project. An overview of the history is provided below, and an in-depth account is provided as Appendix B, Seismic Legislation History. A timeline is provided on the following page as Figure 3-1.

Earthquake policy making in the region began in response to the combination of civil society pressure and the 1933 Long Beach Earthquake. Changes to the building code were quickly adopted in cities across the Los Angeles region in response to the earthquake. Further changes to the City of Los Angeles' Building Codes were adopted following the subsequent major earthquakes of 1971 (San Fernando), 1989 (Loma Prieta), and 1994 (Northridge).[37] In the period between the mid-1970s and mid-1980s, far-reaching policies were adopted by municipalities and

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[32] City of Los Angeles, Municipal Code, Sec. 91.9501 http://www.amlegal.com/los_angeles_ca/ (accessed February 12, 2008).

[33] City of Los Angeles, Municipal Code, Sec. 91.9502 http://www.amlegal.com/los_angeles_ca/ (accessed February 12, 2008).

[34] City of Los Angles, California. Council File Index 04-0092, http://cityclerk.lacity.org/CFI/ (accessed November 11, 2007).

[35] City of Los Angles, California, CFI 07-0144, http://cityclerk.lacity.org/CFI/ (accessed November 11, 2007).

[36] For example, Carl-Henry Geschwind (2001) Robert S. Yeats (2001), and Dan Alesch & William Petak (1986).

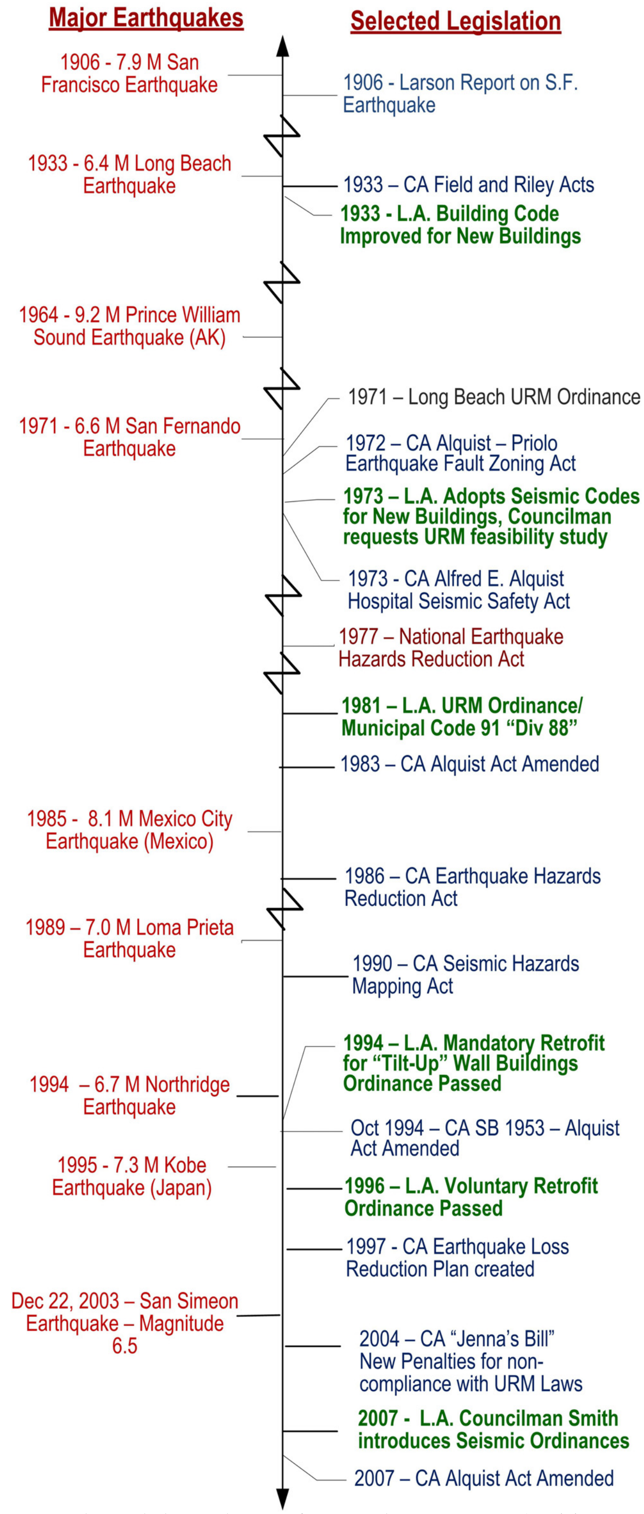
[37] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001): 111.

the state. The standardization and steady advancement of code was achieved through the Uniform Building Code; hospital safety across the State of California was addressed through the 1973 Alquist-Prieto Act; insurance, land use and construction were regulated in the *California Earthquake Hazards Reduction Act of 1986*. The substantial strides made during this period ensured that new buildings would be safe for their occupants.

Following this period, seismic safety government intervention continued, the focus of policies often shifting to the existing building stock. Following the lead of Long Beach and Los Angeles, the State of California began to encourage the retrofitting of URM buildings through SB 657. The retrofitting of hospitals was mandated in 1994 with State Bill (SB) 1953. The City of Los Angeles also mandated that "tilt-up" buildings be retrofitted, and introduced a range of voluntary retrofit ordinances during the late 1990s.

It is clear that policies are often adopted in reaction to major earthquakes. However, this is only the beginning of a much longer process. Further related policies may be adopted in turn, and the implementation of all policies is commonly a protracted and evolving process.[38], Therefore, policy makers are not, and should not be, bound to reactive policy making in this area. Policies adopted in response to a major earthquake will have come too late to save lives and prevent economic losses, and may still take years to pass, even after a major seismic event.

Figure 3-1. Timeline of Selected Events



[38] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001): 5.,;Daniel Alesch, & William H. Petak, *Overcoming Obstacles to Implementing Earthquake Hazard Mitigation Policies: Stage 1 Report*, (MCEER, 2001).

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4 PROPOSED POLICIES

Two proposed government policy interventions were considered. These are:

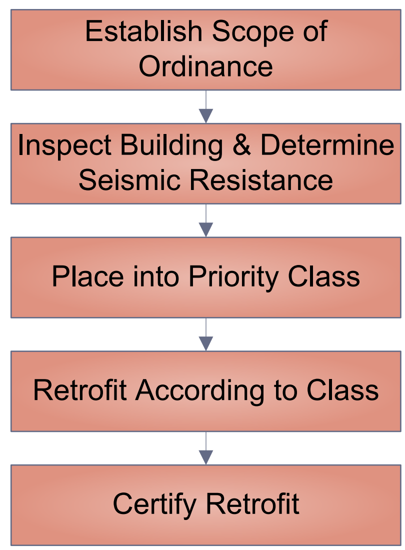
1. Local government legislation mandating retrofitting of non-ductile concrete structures.
2. Local government legislation establishing a program in which building owners disclose their non-ductile concrete structure's risk using publicly posted signs or placards. This project considers both a voluntary and a mandatory placard program.

Each proposed policy warrants careful examination. We first look at those elements which are similar for the two policies. We then examine the policies and their interior options in detail and provide an initial analysis of the placard policy, narrowing the number of policies being considered. Finally, we address the legality of the proposed policies.

4.1 Common Features of the Proposed Policies

The two policies would have similar basic structures. They both require: the establishment of the scope of the ordinance; an inspection of a building and a determination of its seismic resistance; the placement of the building in a priority class; the retrofit of any sub-standard building; and, the certification of a completed retrofit. These steps are based on the existing ordinances for URM and non-ductile concrete buildings in the City of Los Angeles and other California municipalities.

Figure 4-1. Ordinance Steps



4.1.1.1 Determination of Scope

The first step will be to reach a determination on exactly which buildings will be affected under the new rule. This may be a broad category, such as that used by the City of Santa Monica in its municipal code, which mandates the retrofit of non-ductile concrete buildings. [39]

There are two ways to categorize buildings which can then be used to phase in legislation. Buildings can be divided into priority classes. URM and similar legislation tend to divide by priority type, placing life safety buildings, such as schools and hospitals first, followed by high occupancy buildings, leaving the buildings with the lowest occupancy levels as the last phase of the legislation. Another approach this issue is to identify the weakest types of non-ductile concrete structures. For example, those with soft-story attributes are at particularly high risk of failure.[40] In this case, as noted by EERI President Craig Comartin, it is

[39] City of Santa Monica. Municipal Code, 8.80.020. http://www.qcode.us/codes/santamonica/main.php (accessed March 3, 2008).

[40] Farzad Naeim, Structural Engineer and Legal Counsel, John A. Martin & Associates, interviewed by the authors on March 27, 2008.

possible that only 5-10 percent of the non-ductile concrete buildings in the city would be classified as extremely vulnerable to structural failure during an earthquake.[41]

4.1.1.2 Timeline for Retrofit

Each policy would be implemented over a period of years, and would include phasing elements similar to those already in the City of Los Angeles' and other municipalities' building codes. A ten-year period for both policies is used for the cost-benefit analysis.

4.1.1.3 Building Inspections to Determine Seismic Resistance

Once a scope is determined the targeted buildings will need to be inspected to determine if they are, in fact, at risk. Some buildings will be within the scope, but due to existing retrofitting or perhaps a forward thinking architect, in fact be seismically stable.[42] Additionally these buildings are not necessarily easily identified by sight. If the building plans are not available structural investigation may be required.[43] In the implementation of the URM ordinance, the City of Los Angeles would bore these costs. However, other cities have placed the inspection burden and fee onus on the building owner. Once the seismic status is known, the building would be placed within delineated classes, and acted upon accordingly.

4.1.1.4 Retrofit and Certification

The owners of buildings within certain classes would be required to retrofit those buildings to seismic standards within the specified time period. FEMA divides buildings into four classes as shown in Table 4-1.[44] The city can determine the level of retrofit that they wish the buildings to reach, however, "Life Safety" may prove adequate. Once a building has been retrofitted, the city will need to inspect the building or its plans and determine that the retrofit has in fact, made it seismically resistant. The city would then provide some type of certification to that effect.

Table 4-1. Performance Levels

Objective: Standard	Description of Standard
Fully Operational: Immediate Occupancy	Minimal post-earthquake damage and disruption with some nonstructural repairs and cleanup.
Operational: Damage Control	Protect some feature or function of the building beyond life-safety, such as protecting building contents or preventing the release of toxic materials.
Life Safety: Life Safety	Allows for irreparable damage as long as life is not jeopardized and ingress or egress routes are not blocked.
Near Collapse: Risk Reduction	Rehabilitation of parts or portions of a structure without considering the entire structure for life-safety or greater performance.

[41] Craig Comartin, EERI and Concrete Coalition, interviewed by the authors on March 18, 2008.
[42] Marjorie Green, EERI, interviewed by the authors on February 21, 2008.
[43] Chris Rojahn, Executive Director of Applied Technology Council, interviewed by authors on March 4, 2008.
[44] FEMA, *Typical Costs for Seismic Rehabilitation of Existing Buildings*, (FEMA 156, 1994)

4.2 Retrofitting Mandate

A mandate for retrofit presents only one basic policy; building owners will be required by ordinance to inspect and then make changes to their buildings. This contrasts with a placard policy which has a number of design options.

4.3 Potential Placard Systems

A policy which establishes the use of placards to inform the public of the seismic safety of non-ductile concrete structures presents multiple options. At the highest level, the posting of placards can be voluntary or mandated. Additionally, the content of the placards could range from simple letter grades for all buildings in the scope (such as is done with restaurants in Los Angeles County) to semi-detailed explanations posted only on buildings which might be unsafe (as is generally done for URM buildings). For the purposes of modeling, two variants of placards were selected: 1) placards for all buildings within with positive and negative seismic safety information; and, 2) placards which contain only negative seismic safety information. The four options are presented below:

Figure 4-2. Picture of URM Placard. Picture provided by Claire Clark, Seismic Safety Coordinator, City of San Luis Obispo.

Placard Option 1. Voluntary/All Buildings – Owners whose buildings fall within the scope of the policy are offered the opportunity to post placards proclaiming the level of seismic safety of their buildings.

Placard Option 2. Voluntary/Unsafe Buildings Only – Owners whose buildings fall within the scope of the policy, and are inspected and determined to be unsafe, are offered the opportunity to post placards proclaiming that their building is at risk in an earthquake.

Placard Option 3. Mandatory/All Buildings – Owners whose buildings fall within the scope of the policy are required to post placards proclaiming the level of seismic safety of their buildings.

Placard Option 4. Mandatory/Unsafe Buildings Only – Owners whose buildings fall within the scope of the policy, and are inspected and determined to be unsafe, are required to post placards proclaiming that their building is at risk in an earthquake. (This is the most similar to the policy used by the State of California for URM buildings.)

An additional consideration in designing a placard ordinance is the point in the process at which placards are issued. This is likely to be of concern to policy makers only if Option 4 (Mandatory/Unsafe) is chosen. Placards could be: 1) issued to all buildings which fall within the scope of the policy, placing the onus for proving evidence of seismic resistance on the building

owner; 2) issued only after inspection of a building has determined it to be unsafe; or 3) issued only after an inspection has determined a building to be unsafe and the owner has been provided with an adequate amount of time to retrofit the building.

In the placard system most commonly used in URM ordinances, the jurisdiction identified the buildings that were most at risk, and then provided only those building owners with placards stating that the buildings were unsafe. The issuance of the placards was often implemented in conjunction with ordinances that required the retrofit of the unsafe building. The onus was on the building owner to meet the retrofit guidelines and provide evidence that the required retrofits were completed. Once the retrofit is completed and verified, the placard was removed or replaced with a placard indicating that the building had been retrofitted.

4.3.1 Initial Analysis of Placard Policy

The number of potential placard options requires a preliminary narrowing of options. The only pareto efficient placard policy is that of mandatory seismic warnings on all unsafe buildings. Options 1-3 were found to either cause no significant positive change, or, to present opportunities in which harms outweighed benefits. The justification for dismissal of these policies is provided in Table 4-2, below.

Table 4-2. Removal of Placard Options

Placard Policy Option	Reason for Removal from Consideration
Option 1. Voluntary/All Buildings	Although building owners of seismically stable buildings may post the placards, the similarity of these buildings in appearance to others will present a large population of similar looking non-placarded buildings. Uncertainty will not be lessened, and consumers will remain unable to distinguish between safe and unsafe buildings. The market will not be affected, and the administrative costs of such a program may well outweigh its benefits to society.
Option 2. Voluntary/Unsafe Buildings Only	Experts perceive it to be unlikely that a building owner would voluntarily post a negative seismic safety rating.[45] This would result in no change to the status quo.
Option 3. Mandatory/All Buildings	Requiring all building owners to post placards will create a high administrative cost. Additionally, the similar facades of the buildings to other types of buildings creates the possibility of harming the property values of those buildings which look like the class of buildings placarded but are other types. This includes steel frame buildings, which may or may not be seismically resistant, depending on their construction date and previous exposure to shaking.

[45] This perception is based, in part, on our interview with Farzad Naeim, John A. Martin & Associates, in which he noted that it was unlikely that a placard warning occupants of risk would provide immunity to lawsuits against the building owner in the event of an earthquake.

4.4 Legal Considerations

There are two critical legal considerations for these policies, the legality of either proposed policy and the potential liability of building owners. The City of Los Angeles' URM ordinance provides the basis for the retrofitting mandate policy option. However, as the City has not previously implemented placards for seismic safety considerations, a closer look at the legal considerations is warranted. Additionally, the liability of building owners under a placard ordinance is likely to be of particular concern to that group of stakeholders. The information we provide below about the legislative basis and legal considerations of the proposed policies should not be used in lieu of actual legal consultation.

Jurisdictions in California have the power to offer or mandate a placard program as they have with other seismic strengthening programs. Although the current parameters of URM placards are set by the State (i.e., language, size, font, location) they apply only to those buildings. Additionally, jurisdictions with more aggressive seismic safety programs already in place, such as Los Angeles appear to be exempted from compliance. As only URM placards are included in this State law, the City of Los Angeles should have considerable leeway in designing its program, including setting the conditions by which a placard can be taken down or replaced once a retrofit is completed.

An owner's liability after posting or not posting placards is less clear, and building owners' arguments against placards may include liability issues. It appears that property owners are not released from liability simply because they were unaware of their seismic status. Indeed, it is possible that the duty of a building owner to warn of a seismic hazard already exists, even without a law mandating that a warning be provided.[46] However, a recent court case suggests that not posting a placard with a warning when required to do so will place a property owner at risk. The families of two women killed by falling bricks during the 2003 San Simeon Earthquake were recently awarded $2 million. The owner of the building was held legally responsible for the collapse of the 111-year old URM building. Although the owner had received repeated notifications from city engineers and building officials that the building was known to be at risk of collapsing during an earthquake, the building was never retrofitted and those who worked in the building were not notified of the risk via placard as was required by state law.[47] Although this case probably does not set a precedent for the rest of California, it is based in the legal principle of *res ipsa loquitur*, of negligence which causes harm, and could be replicated elsewhere.[48]

[46] CSSC, *The Right to Know, Disclosure of Seismic Hazards in Buildings.* (1992). No. 92-03. 7

[47] Leah Etling, "San Simeon Quake Trial: Victims' Families awarded $2 million," *San Luis Obispo Tribune*, February 5, 2008 http://www.sanluisobispo.com/572/story/267442.html (accessed April 12, 2008)

[48] Fred Turner, CSSC, Interviewed by the authors on March 29, 2008.

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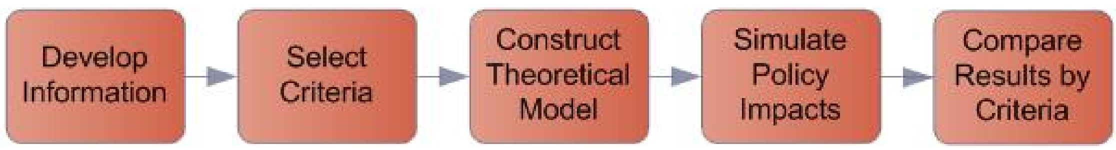
5 METHODOLOGY

This section explains the project methodology. In order to arrive at our recommendations we undertook a five step process: 1) developing information, which includes defining concepts and obtaining data; 2) selecting the criteria by which the results would be compared; 3) constructing theoretical models to map outcomes; 4) simulating the impacts of the policies by entering the information and data into the models; and, 5) comparing the policy impacts by the chosen analytical criteria.

Figure 5-1. Methodology Steps



5.1 Information Development

The information presented in the previous sections was developed using a variety of sources. Print references included academic papers, books, federal and state reports and guides, such as those published by FEMA. Additional sources of note were earthquake-related cost-benefit analyses, histories of previous legislative efforts and municipal and state laws and codes. Many organizations and individuals served as both resources for data and expert guidance. Notable sources include: the California Seismic Safety Commission (CSSC), EERI and the Concrete Coalition, ATC, PEER, SCEC, and Dr. William Petak, Professor Emeritus at USC.

5.2 Criteria Selection

The framework for comparison of the policy options was established early in the research process. As the ultimate goal of either policy is to save lives and lessen economic loss, human safety and economic efficiency were identified as the primary criteria, and can be calculated using a cost-benefit model. Political feasibility and implementation opportunities and constraints are considered. A full definition of each criterion is provided below:

Economic Efficiency - Given finite resources to carry out any policy, the estimation of its costs and benefits is essential. An economically efficient policy will result in the overall economic benefits of the policy outweighing the overall economic costs.

Human Safety - Although many cost-benefit analyses calculate the value of saving lives in terms of the "dollar value of a statistical life," a primary reason for seismic safety policy is to reduce the human cost of earthquakes. Therefore, the number of lives saved and injuries prevented is considered as a distinct criterion, and not included in the economic cost calculations.

Political Feasibility - Any policy is only achievable if the decision makers are willing and able to prioritize its passage and funding above other potential policies. Triggering events, such as major earthquakes, can increase political feasibility, while other conditions, such as budget shortfalls and constituent resistance, can reduce it.

Implementation Opportunities and Constraints – Even if a proposed policy is made into law, its success is still not ensured. Seismic building safety policy implementation requires action on the part of a range of actors including city building and safety departments, building owners, occupants, engineers, architects, and other government officials. If any vital group of stakeholders resists the implementation of the policy, its effectiveness may be greatly reduced.

5.3 Constructing the Theoretical Model

Estimating actual dollar values of policy outcomes is extremely valuable in comparing policy options. This is especially true when the future contains uncertainty, as with seismic policy. A cost-benefit analysis model is used to determine the economic and human safety impacts of the proposed policies. An overview of the cost-benefit analysis model is provided at the end of this section, in Figure 5-2, Project Decision Tree. The model includes a sub-model, which represents a building owner's decision to take a specific action as a result of a policy option being implemented.

5.3.1 Cost Benefit Analysis Model

Cost-benefit analysis is a commonly used policy analysis tool. The essential function is to weigh the monetized social costs and benefits of policy outcomes as they deviate from the status quo. Although this model was somewhat simplified, it provides the ability to make calculations about the future. This follows the practice described by Richard Zerbe and Anthony Falit-Baimonte in their 2001 paper.[49] This project uses model "mapping" to simplify the multitude of options and produce a set of manageable outputs. As shown in Table 5-l, benefits and costs are separated for ease of calculation and analysis. The complete process is described in Appendix C, Methodological Technical Appendix.

The cost-benefit model compares the policy impacts against the state of nature for each criterion. For example, retrofitting all vulnerable non-ductile concrete structures would reduce the risk of economic loss after earthquake, yet would incur certain administrative, retrofitting and business interruption costs. If an earthquake were to occur after the retrofit took place, the policy benefits could be estimated in terms of the economic loss prevented. Although both probabilistic and deterministic outcomes can be calculated, this project uses probabilistic calculations which weigh the likely outcomes of an uncertain event over a given number of years.

Clarifying Terms

Outcome Mapping: *A preliminary exercise in decision modeling, where all possible outcomes are theorized and evaluated. From this process, simpler abstract models of outcomes may be discerned.*

[49] Richard O. Zerbe & Anthony Falit- Baiamonte, *The Use of Benefit-Cost Analysis for Evaluation of Performance-Based Engineering Decisions.* PEER Report No. 2002/06. (2001); 8

Table 5-1. Benefits and Costs

	Benefits	Costs
	Reduced losses which otherwise would have been caused by an earthquake.	Cost to society of implementing the policy.
Economic	• Reduced cost of replacement • Reduced business interruption	• Administrative costs • Retrofit costs • Cost of displaced occupants
Human Safety	• Injuries avoided • Deaths avoided • Other effects (such as trauma) avoided	• None

5.3.2 Business Owner Decision Making Sub-Model

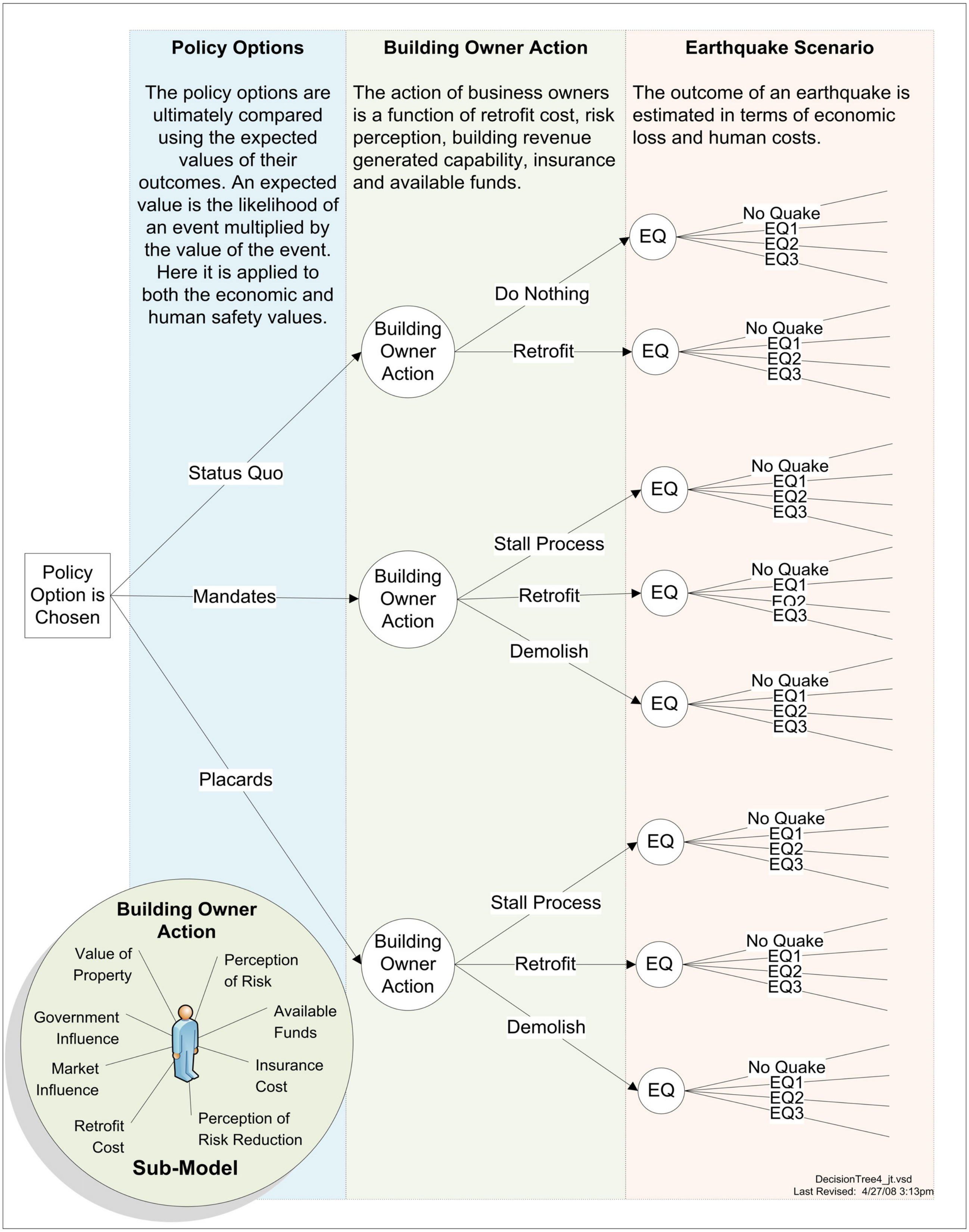
In assessing the impact of the policy alternatives, it is necessary to understand the reactions of building owners. Building owners will make many decisions which impact the success of any policy option, the critical decision being what action to take regarding the earthquake hazard. Currently, in the "status quo," the building owner has three basic available options to reduce risk: do nothing, take out insurance, and retrofit.[50] Retrofitting requires the expenditure of funds and results in an uncertain reduction of economic and human safety risk. Such activities are influenced to varying degrees by the value of the property (building and land), the revenue generating capacity of the property, the funds available to the building owner, and the building owner's risk perception. This model uses these inputs to project what building owners are likely do to in response to a policy option, and uses that output to determine the number of impacted buildings in the cost-benefit model. The detailed explanation of the design and inputs for this sub-model is also provided in Appendix C, Methodological Technical Appendix.

5.4 Simulation

The model was developed in Microsoft Excel. It provides an interactive, user-friendly, simulation of the proposed policy impacts. This simulation tool is sensitive to various inputs and the related uncertainties, and is available upon request. The outputs of the simulation are presented in terms of the criteria of economic efficiency (net benefit) and human safety (avoided deaths and injuries), and are provided in Section 6, Results.

[50] These second two options may be conducted in tandem. The building owner could also demolish the building to develop a new structure.

Figure 5-2. Project Decision Tree



6 RESULTS

Both potential policies were analyzed using the methodology provided above in Section 5. The analysis supports the adoption of legislation to encourage the retrofitting of privately owned buildings using either mandates or mandatory seismic warning placards. If the City of Los Angeles were to adopt a mandate to retrofit non-ductile concrete buildings, there would be a risk-adjusted overall net benefit to the city of $56.4 million, saving 5 lives and preventing 56 injuries. If it were to adopt a mandatory detailed placard ordinance, there would be a risk-adjusted overall net benefit to the city of $10.7 million, saving 1 life and preventing 11 injuries. However, these results must be balanced with the other analytical criteria. The criteria analysis matrix on the following page shows that there are tradeoffs to be made between the mandated retrofit policy option, which would achieve greater reductions in deaths, injuries and economic costs, and a placard policy option, which would involve lower certain costs, less political resistance, and fewer implementation constraints. There are a few additional implications for the results, including the influence of potential incentives and social justice impacts of the policies, these are addressed in Section 6.4, Additional Impacts.

6.1 Mandated Retrofits

The results from the baseline model show overall economic benefits of $56.4 million, a benefit-cost ratio of 2.75, with 56 injuries avoided, and 5 lives saved. The breakdown of benefits and costs, and modeling assumptions used, is provided in Table 6-1, below.

Table 6-1. Mandated Retrofits Baseline Results

<table>
<tr><th>Scenario Details</th><th colspan="3">Benefit-Cost Analysis Results</th></tr>
<tr><td rowspan="13"><u>State of Nature</u>
• City has 2,000 NDCS
• 5% of those are vulnerable
<u>Policy Features</u>
• First year of policy is 2009
• Only the vulnerable (5%) retrofit
• Retrofits evenly distributed over first 10 years
<u>Earthquake</u>
• Magnitude of 6.7
• 67% likely in 30 years
• Time of day is 3:00 p.m.
<u>Time Frame</u>
• 30 years
<u>Discount Rate</u>
• 10%</td><td>Itemization</td><td>Benefits</td><td>Costs</td></tr>
<tr><td>Replacement Costs</td><td>$7.2m</td><td></td></tr>
<tr><td>Business Interruption</td><td>$81.4m</td><td></td></tr>
<tr><td>Administrative Costs</td><td></td><td>$1.1m</td></tr>
<tr><td>Retrofit Costs</td><td></td><td>$20.8m</td></tr>
<tr><td>Displacement Costs</td><td></td><td>$10.4m</td></tr>
<tr><td>Total Economic Benefits</td><td>$88.7m</td><td></td></tr>
<tr><td>Total Economic Costs</td><td></td><td>$32.3m</td></tr>
<tr><td>Net Benefits</td><td colspan="2">$56.4m</td></tr>
<tr><td>Benefit/Cost Ratio</td><td colspan="2">2.75</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Prevented Injuries</td><td colspan="2">56</td></tr>
<tr><td>Prevented Deaths</td><td colspan="2">5</td></tr>
</table>

Table 6-2. Criteria Analysis Matrix

Policy	Cost Efficiency		Effectiveness and Human Cost		Political Feasibility	Implementation Issues and Constraints
Retrofit Mandate	A retrofit mandate policy requires certain costs (retrofit, administrative, and business displacement costs), to be balanced with uncertain avoided losses (business interruptions, replacement costs, and debris removal).	Total Benefits: **$88.7 million** Total Costs: **$32.3 million** Overall savings: **$56.4 million**	A mandate retrofit would lessen the number of deaths and injuries, although public trauma would not be eliminated.	Injuries Avoided: **56** Deaths Avoided: **5**	Cost is the major constraint for the city government and building owners alike. Currently, the city has a budget deficit, and businesses are witnessing an uncertain economic climate. Many are willing to risk the uncertain losses an earthquake may bring and prioritize spending elsewhere.	The city would have to channel resources into the program. Building owners, would need to obtain the necessary funding, and would have to evaluate the revenue stream and future plans for the property. Many would retrofit, but some would vacate the building or even demolish it. Any such action would place burdens on the current building occupants, whether businesses or residents.
Placard	A mandate placard would alert the public to vulnerable structures and may encourage retrofitting if owners lost business. The city would pay for the placards.	Total Benefits: **$17.7 million** Total Costs: **$7.0 million** Overall savings: **$10.7 million**	A mandate placard would reduce the number of deaths and injuries, yet far fewer than a mandate retrofit policy. Public trauma would not be eliminated. There would be relatively less business lost as a result of a placard.	Injuries Avoided: **11** Deaths Avoided: **1**	Building owners and their tenants may be resistant to enforced hazard notification because they could lose business. It could also lead to a more costly mandated retrofit policy. City officials may not support a placard program due to costs.	This option would be easier to implement than the retrofit mandate and the city would have to channel fewer resources to it. For the policy to achieve notable human safety risk reductions, the city would have to engage actively with the building owners. For building owners, there would be far fewer certain costs compared with the retrofit mandate.

6.2 Placards

The placards policy option would result in fewer buildings being retrofitted than the mandate option. Using a high-end estimate, in which 20% of the building owners retrofit, the results from the baseline model show overall economic benefits of $10.7 million, a benefit-cost ratio of 2.53, with 11 injuries avoided, and 1 life saved. The breakdown of benefits and costs, and the modeling assumptions used, is provided in Table 6-3, below.

Table 6-3. Placards Baseline Results

<table>
<tr><th>Scenario Details</th><th colspan="3">Benefit-Cost Analysis Results</th></tr>
<tr><td rowspan="13"><u>State of Nature</u>
• City has 2,000 NDCS
• 5% of those are vulnerable
<u>Policy Features</u>
• First year of policy is 2009
• Only the vulnerable (5%) would consider retrofitting
• 20% of vulnerable do in fact retrofit
• Retrofits evenly distributed over first 10 years
<u>Earthquake</u>
• Magnitude of 6.7
• 67% likely in 30 years
• Time of day is 3:00 p.m.
<u>Time Frame</u>
• 30 years
<u>Discount Rate</u>
• 10%</td><td>Itemization</td><td>Benefits</td><td>Costs</td></tr>
<tr><td>Replacement Costs</td><td>$1.4m</td><td></td></tr>
<tr><td>Business Interruption</td><td>$16.3m</td><td></td></tr>
<tr><td>Administrative Costs</td><td></td><td>$0.8m</td></tr>
<tr><td>Retrofit Costs</td><td></td><td>$4.2m</td></tr>
<tr><td>Displacement Costs</td><td></td><td>$2.1m</td></tr>
<tr><td>Total Economic Benefits</td><td>$17.7m</td><td></td></tr>
<tr><td>Total Economic Costs</td><td></td><td>$7.0m</td></tr>
<tr><td>Net Benefits</td><td colspan="2">$10.7m</td></tr>
<tr><td>Benefit/Cost Ratio</td><td colspan="2">2.53</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Prevented Injuries</td><td colspan="2">11</td></tr>
<tr><td>Prevented Deaths</td><td colspan="2">1</td></tr>
</table>

6.3 Sensitivity Analysis

This sensitivity analysis explores the variability within the model by altering individual assumptions of the baseline scenario and holding all other others constant. This process identifies the amount each data point or assumption can be varied and the variation's impact upon the results. This is especially useful when considering the policy ramifications of a more severe, but lower probability earthquake, or changing the number of buildings.

6.3.1 Mandate Policy Sensitivity Analysis

The sensitivity analysis reveals that the key variables are the number of buildings, the implementation rate and the probability and magnitude of the simulated earthquake. First, if the number of existing buildings is less than 600, this policy is no longer cost-beneficial. This is notable as the low-end estimate of non-ductile concrete building numbers in the city is 500. Second, if only those buildings which are most vulnerable are affected by the policy the costs will be limited for the city and for building owners, yet the economic and human safety benefits

remain high. Third, the implementation rate has a smaller than expected impact on the overall results. This suggests that the decisions made by building owners are less important than previously thought, as long as a critical mass of retrofitting is achieved. However, a well-structured policy would lead to savings for the city and building owners alike. Fourth, when looking at specific costs, retrofit and business interruption costs have a relatively large impact on the model, while displacement, administrative, and replacement costs have a smaller impact. Of these aspects, business interruption costs are particularly important to examine more closely because they form a major portion of the benefits, and because the evolving economy and desire to recoup business losses may mitigate many of the potential opportunity costs.

6.3.2 Placard Policy Sensitivity Analysis

The sensitivity results for the placards policy are similar to those of the mandate policy. For most cases, similar changes in the baseline assumptions must be applied to change the overall decision. For example, the placard policy requires that there be no fewer than 700 non-ductile concrete structures for the policy to be cost-beneficial. The same applies if retrofit costs are increased by more than 270 percent, or if business interruption costs are reduced to less than 35 percent. As with the mandate policy, information is important. If 10 percent of non-ductile concrete buildings are really vulnerable, and more than 49 percent of all non-ductile concrete buildings are included in the policy, the policy will no longer be cost-beneficial.

6.3.3 Sensitivity Results for Specific Variables

The sensitivity results for specific variables are presented below. Many of the results are presented in tabular format, however, a number of tables are provided in Appendix C.

Earthquake Magnitude – The larger the magnitude of the earthquake, the greater the damage. However, due to the decreasing probability of occurrence, larger earthquakes will have a smaller statistical impact. For example, a 6.7 magnitude earthquake would result in 5 deaths and 56 injuries over the next 30 years, while an 8.0 magnitude earthquake would result in no deaths and 2 injuries over the same period. This is due to the low probability of higher magnitude earthquakes. The magnitude of the earthquake impacts only the benefits side of the model. Hence, while likely benefits decrease, costs remain the same. [51]

Earthquake Probability - The 67 percent probability of a 6.7 magnitude earthquake occurring in Los Angeles, as provided in the recently published USGS report, is a midpoint of a range of likely values.[52] Testing the impact of this range on the model reveals that the likelihood of a 6.7 magnitude earthquake would have to decrease significantly, to a less than 29 percent chance, in order for the mandate policy to not be cost-beneficial. However, even with a 29 percent change, lives would be likely to be lost. This suggests that the margin of error of the SCEC predictions would have to be very large for the potential mandate policy to be disregarded on economic grounds alone. Similar results are present for the placard policy option in Table 6-4.

[51] If it were possible to be certain that an earthquake of a specific size and location would occur in a given year, the benefit-cost model would return a very high benefit-cost ratio for a large magnitude earthquake.

[52] Edward H. Field, et al, *The Uniform California Earthquake Rupture Forecast, Version 2* (United States Geological Survey, 2008).

Table 6-4. Magnitude and Probability Sensitivity Analysis

Sensitivity - Magnitude and Probability			
Magnitude	6.7	7.0	8
Probability	67%	20%	1%
Results for Mandates			
Net Benefits	$56.4m	$63.3m	-$24.5m
B-C Ratio	2.75	2.96	0.24
Injuries Prevented	56	18	2
Deaths Prevented	5	2	0
Results for Placards			
Net Benefits	$10.7m	$10.7m	-$5.4m
B-C Ratio	2.53	2.53	0.22
Injuries Prevented	11	4	0
Deaths Prevented	1	0	0

Number of Buildings - Given the uncertainty over the number of non-ductile concrete buildings within the City of Los Angeles, this is a critical aspect of the sensitivity analysis. The number of buildings has a substantial impact on the overall model, as it impacts both the costs and benefits. As the number of buildings increases, so does the overall economic and human safety benefit of the policy. However, when the number of buildings falls below 600, the mandate policy is no longer cost-beneficial (700 is the tipping point for the placard policy). This is important because the low-end of the estimated range of buildings is 500. Although a single life is likely to be saved, which in itself could be worth the investment, the low economic payback is concerning and leaves the process vulnerable to critical error due to inaccurate estimation of costs and benefits elsewhere. The sensitivity results for this item are shown below in Table 6-5.

Table 6-5. Number of Buildings Sensitivity Analysis

Sensitivity - Buildings			
Total Buildings	500	2,000	3,000
Results for Mandates			
Net Benefits	$-1.2m	$56.4m	$145.7m
B-C Ratio	0.85	2.75	4.01
Injuries Prevented	14	56	84
Deaths Prevented	1	5	8
Results for Placards			
Net Benefits	$0.4m	$10.7m	$28.3m
B-C Ratio	0.79	2.53	3.7
Injuries Prevented	3	11	17
Deaths Prevented	0	1	2

Vulnerability of Buildings - An important aspect of the model is the percentage of non-ductile concrete buildings that are most vulnerable to structural failure during larger to high magnitude earthquakes. Structural engineers Comartin and Farzad Naiem both suggest that between 5 and

10 percent of non-ductile concrete buildings are the most dangerous, the causes of which are described in detail in Section 2. [53] The baseline scenario assumes that 5 percent of buildings are vulnerable. Increasing this figure to 10 percent for the mandate policy option doubles the number of likely deaths and an injury avoided, to 11 and 112 respectively, and increases the benefit-cost ratio to 5.27. The same general rule applies to the placard policy option. This would suggest that it is critically important that the City of Los Angeles Department of Building and Safety is able to identify the numbers of vulnerable buildings. It would be more costly to the city and building owners alike if the policy were to cover all non-ductile concrete buildings rather than simply the most vulnerable. If between 5 and 10 percent of non-ductile concrete buildings are vulnerable, and yet 100 percent are required to retrofit, then the economic costs will substantially outweigh the benefits, and human safety is unlikely to be improved. This is equally important for the placard policy option.

Table 6-6. Vulnerable Buildings Sensitivity Analysis

Sensitivity - Vulnerable Buildings			
Total Buildings	2,000	2,000	2,000
% of Total is Highly Vulnerable	5%	10%	5%
% of Total Required to Retrofit	5%	10%	100%
Results for Mandates			
Net Benefits	$56.4m	$275.7m	$-305.6m
B-C Ratio	2.75	5.27	0.52
Injuries Prevented	56	112	112
Deaths Prevented	5	11	11
Results for Placards			
Net Benefits	$10.7m	$54.1m	-$72.0m
B-C Ratio	2.53	4.86	0.49
Injuries Prevented	11	22	22
Deaths Prevented	1	2	2

Discount Rate - The discount rate of 10 percent was chosen because of its use by a number of government agencies, such as the U.S. Office of Management and Budget. These agencies use the 10 percent rate to reflect the high opportunity costs faced by private investors, which contrast the lower opportunity costs of government agencies. For these policy options, as both benefits and costs are potentially experienced over time, changing the discount rate alters the magnitude of the overall benefits experienced, but does not change the result to a negative one. This is demonstrated in Table 6-7.

[53] Craig Comartin, EERI and Concrete Coalition, interviewed by the authors on March 18, 2008.

Table 6-7. Discount Rate Sensitivity Analysis

Sensitivity - Discount Rate			
Discount Rate	6%	10%	13%
Results for Mandates			
Net Benefits	$102.3m	$56.4m	$37.3m
B-C Ratio	2.75	2.75	2.27
Injuries Prevented	56	56	56
Deaths Prevented	5	5	5
Results for Placards			
Net Benefits	$19.9m	$10.7m	$6.9m
B-C Ratio	3.47	2.53	2.09
Injuries Prevented	11	11	11
Deaths Prevented	1	1	1

Implementation Rate - As highlighted by the 1981 URM retrofit ordinance in the City of Los Angeles, the 1994 California Hospital seismic retrofit bill (SB 1953), and the statewide experience with placard ordinances, seismic policy can take a considerable amount of time to implement. The time frame will largely depend on the number of non-ductile concrete buildings included within the policy, the performance standard they are retrofitted to, and the length of the time period building owners are given in which to make retrofits. As these are factors controllable by the policy makers, it is assumed that a reasonable time frame, which reflects past experience, will be employed. The baseline scenario for the model assumes that the ordinance would be fully implemented within 10 years at even rate (20 buildings per year, over 10 years). Alternative implementation scenarios, presented in the table below, show that the policy is likely to remain cost-beneficial. This analysis also suggests that the building owner decision sub-model has a limited impact on the mandate policy impact. In contrast, the placard policy option outcomes are likely to be more impacted by the building owner decision sub-model.

Table 6-8. Rate of Retrofit Sensitivity Analysis

Sensitivity - Rate of Retrofit						
Years to Retrofit	10	20	20	10	10	10
Rate	Even	Even	Declining	Even	Even	Even
Details	20/yr	10/yr	10 in 1st year, decline to 1 in 20th year	Begin after 5 years (2014), 10/yr	Begin after 20 years (2028), 10/yr	Only half of buildings, begin after 10 years, (2018), 10/yr
Results for Mandates						
Net Benefits	$56.4m	$36.4m	$84.7m	$31.9m	$2.3m	$20.4m
B-C Ratio	2.75	2.62	2.71	2.59	1.44	2.62
Injuries Prevented	56	45	57	45	14	25
Deaths Prevented	5	4	5	4	1	2
Results for Placards						
Net Benefits	$10.7m	$11.7m	$16.9m	$6.0m	$0.4m	$3.7m
B-C Ratio	2.53	2.39	2.50	2.39	1.33	2.31
Injuries Prevented	11	9	11	9	3	5
Deaths Prevented	1	1	1	1	0	0

Retrofit Costs - Estimates for the retrofit costs are based upon distributions of empirical retrofit costs data in *FEMA 156*. [54] Sensitivity analysis shows that the impact of these cost distributions on the overall model is important. Indeed, if costs were greater than 2.8 times higher than estimated (2.7 times higher for the placard option), then the mandate policy would no longer be cost beneficial, and would also be more sensitive to changes in other variables. It is important to note, however, that such increases would not affect the numbers of deaths and injuries avoided by the policy.

Table 6-9. Retrofit Costs Sensitivity Analysis

Sensitivity - Retrofit Costs			
Costs	Average	2.x Average	3.x Average
Results for Mandates			
Net Benefits	$56.4m	$25.2m	-$6.0
B-C Ratio	2.75	1.40	0.94
Injuries Prevented	56	56	56
Deaths Prevented	5	5	5
Results for Placards			
Net Benefits	$10.73m	$4.5m	-$1.7m
B-C Ratio	2.53	1.34	0.91
Injuries Prevented	11	11	11
Deaths Prevented	1	1	1

Administrative Costs - Estimations for the mandate administrative costs are based on data for the 1981 URM building ordinance in Los Angeles, and are calculated based on the number of buildings included in the policy.[55] These costs are spread across 10 years, along with additional program start-up cost equaling 40 percent of the overall costs. Placard policy costs are assumed to be 70 percent of the mandate administrative costs. As these costs are a smaller portion of the aggregate policy costs to all stakeholders, they do not significantly impact the results. Mandate administrative costs would have to be 53 times higher to make the program more economically costly than beneficial overall. Placard administrative costs have a greater impact, yet would still have to be 15 times higher to make the benefit-cost ratio less than one.

Displacement Costs – Displacement costs are those costs incurred when occupants (owners or tenants) must temporarily vacate their workplaces or residences due to retrofitting activities. For the baseline model, displacement costs are assumed to be 50 percent of retrofit costs. This estimate is based on our interview with Comartin of EERI, and is at the high end of the suggested range.[56] As this is a smaller portion of the aggregate societal policy costs, it is unsurprising that the displacement costs must be increased by over 6 times in order for the mandate policy to no longer be cost-beneficial. The placard policy option requires a similar magnitude of change.

[54] FEMA, *Typical Costs for Seismic Rehabilitation of Existing Buildings,*" (FEMA 156, 1994).

[55] Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986): 109-112

[56] Craig Comartin, EERI and Concrete Coalition, interviewed by the authors on March 18, 2008.

Business Interruption Costs - Business interruption costs are estimated on the basis of data in *ATC 13*, which predicts the average number of days it will take for buildings from certain social functions to be fully restored. This figure is then combined with estimations for the numbers of individuals within each building, also from *ATC 13*, along with an estimate by economist John Quigley for the cost per occupant per day of lost business.[57,58] As this is a major portion of the economic benefits (as costs avoided), it is important to sensitize this appropriately. It is also important because recent economic modeling research suggests that social phenomena such as the digital revolution have enabled businesses to become less dependent on the buildings that house them.[59] Moreover, it is likely that businesses will increase output as soon as possible after an earthquake in order to recoup losses. Nonetheless, business interruption costs included in the model would have to decrease to less than 30 percent for the mandate policy (35 percent for the placard policy) to no longer be cost-beneficial.

6.4 Additional Impacts

The consideration of the potential influence of incentives for building owners to retrofit and potential impacts of the proposed policies on social justice also warrant examination. The project team did not explicitly consider tax breaks (which would need to occur at the State level), government subsidized loans or other financial incentives for property owners. However, during the information development stage of the project the team encountered anecdotal data and historical information on financial incentives, such as government loans and waiving of permit fees. Government subsidized loans for retrofitting have been offered at various times during the URM policy-making process. However, these pools of funding have rarely been utilized by the private sector. Financial regulation barriers and governmental red-tape were cited as reasons for non-utilization. Waiving of permitting fees may be more successful, the City of San Luis Obispo attributes some of its success with its URM program its policy of allowing building owners to pay only the retrofit permitting fees for all work conducted on their buildings during the retrofitting process.[60]

The social justice implications of the proposed policies are uncertain. The impact of the policy on low-income and disadvantaged groups cannot be determined without accurate tally of these buildings and understanding of income levels of their occupants. If the policies are successful, it would be possible that the values and rents of previously risky properties would be increased.[61] This has two potentially negative impacts. First, renters may be priced out of the market, with those in lower socio-economic groups more likely to be affected. Second, the cost of retrofitting may exceed the increase in property value. This is more likely to affect those persons in lower socio-economic groups.

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[57] *Applied Technology Council Earthquake Damage Evaluation Data for California* (ATC, 1985),

[58] Quigley, J.M. "Earthquake! The Use of Economic, Engineering, and Statistical Information to Invest in Seismic Safety." *Japanese Journal of Regional Economics*, 3, 1998: 9-20.

[59] Peter Gordon, Harry Richardson and Soojung Kim, *Where Americans Live, Work and Do Business: Thirty-Five Year Trends*, http://www-rcf.usc.edu/~pgordon/pdf/20080325whereamericanslive.pdf (accessed on April 10, 2008).

[60] Claire Clark, City of San Luis Obispo, interviewed by the authors on March 18, 2008.

[61] Gayer, T., Hamilton, J.T., & Viscusi, W.K. (2000, August). "Private Values of Risk Tradeoffs at Superfund Sites: Housing Market Evidence on Learning about Risk." *The Review of Economics and Statistics*, 82(3), 439–451.

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7 RECOMMENDATIONS

The project team recommends that a policy be developed to address the problem of non-ductile concrete buildings failing during an earthquake and causing economic and human loss. Our analysis of empirical data and expert opinion shows that either a retrofit mandate or seismic warning placard program would avoid deaths, injuries, and economic loss. Of the two policy options, a mandate would be far more effective at reducing such losses. Given that the City of Los Angeles has budget constraints, and that businesses are witnessing an uncertain economic climate, the policy should aim to be as inexpensive as possible. Specific recommendations to limit expenses are provided below. Ultimately, we urge policy makers to avoid waiting for a major earthquake to occur before adopting a policy.

The results of the analysis show that City of Los Angeles **should develop a policy to increase the numbers of non-ductile concrete structures that are retrofitted**. A mandate retrofit policy would likely provide the greatest gains to society, with risk-adjusted overall economic benefits of $56.4 million, and the avoidance of 5 deaths and 56 injuries. While a placard ordinance would likely achieve overall economic benefits to the city of $10.7 million, and save 1 life and 11 injuries, the authors are concerned about the effectiveness of such a policy. Both policies are also likely to be constrained by political resistance and implementation barriers. Therefore, we propose a number of cost-saving recommendations:

Develop a flexible and feasible time frame for implementation. Policy design must take implementation into consideration. Because the success or failure of the proposed policies relies in a large part on the actions of private sector building owners, their interests and actions must be considered in policy design. We also recommend the establishment of a steering committee or task force of stakeholders to guide the design and implementation process. It should include politicians, representatives of city departments, seismic experts, engineers and architects and most importantly, representatives of building owners <u>and</u> actual building owners.

Specifically, we provide the following suggestions:

1. **Allow a grace period of 5 years for buildings to be retrofitted.** This period would allow building owners to evaluate their situation, for definitions to be agreed upon, and for information to be gathered by the city. Results shows that such a grace period would not affect the cost-beneficial nature of the policy.
2. **Overlap the mandate with a placard program.** For example, placards could be mandated for lower vulnerability buildings, while higher vulnerability buildings would be required to be retrofitted.
3. **Split implementation into distinct periods.** The less vulnerable buildings could be dealt with in later stages, to allow for the “low hanging fruit” to be addressed in a more cost effective manner. As these buildings make up the largest portion of all non-ductile concrete buildings, it may significantly reduce cost.

4. **Identify vulnerable non-ductile concrete buildings.** This would involve several steps:
   - Agree upon a clear definition of non-ductile concrete buildings including identifying characteristics, distinct structural categories, vulnerable types, and common structural vulnerabilities.
   - Develop an inventory of non-ductile concrete buildings within the City of Los Angeles.
   - Identify those non-ductile concrete buildings which are most vulnerable, including assessments of building usage to identify human and economic costs of structural failure.
5. **Adopt rules which require minimum standards for retrofits.** As discussed above, there are four potential levels of hazard mitigation for retrofit construction. The minimum level, those achieving "life safety" would, will ensure human lives are saved, while maintaining the lowest costs. Business interruption costs and replacement costs may still be experienced, but at a lower level than without retrofitting. This would allow the building owners more flexibility to balance investments with future risks.

Placards are more effective when mandated rather than voluntary. Placards serve to increase the knowledge of all stakeholders, including building owners and investors, building occupants, and insurance companies, and allow them to make better informed decisions about the risk related tradeoffs they face. The more vulnerable buildings the city can include in the program, the more effective the program will be. A low uptake would in turn have a minimal impact on building owners' decisions to retrofit, and result in limited reductions to economic and human loss during earthquakes.

Placards for non-ductile concrete buildings would be more effective when displaying seismic warnings than positive messages. Positive message placards have been effective in the environmental (Leadership in Energy and Environmental Design [LEED] program) and restaurant (hygiene grade posters) fields, however, both examples are universal and have been linked to a broader set of messages and incentives.[62] Building safety placards for non-ductile concrete structures would not achieve the same effects as these programs because the placards would not apply to all buildings.

7.1 General Recommendations

There is a careful balance between having an adequate amount of time to develop a well reasoned and implementable policy, and ensuring that the process takes place. We recommend that policy makers:

[62] The LEED program placards identify "green" buildings, with the implication that all other buildings are not environmentally sustainable. Moreover, incentives are provided to the property owners by government. The restaurant grade placards identify the relative hygiene standards of the establishment.

Expect the process of creating a new policy to take time as stakeholders are educated and definitions are reached. The issue of seismic safety of non-ductile concrete buildings is relatively new to persons outside of the seismic safety arena. Even within the network of experts, there is not a single explanation of which buildings should be categorized this way, and which are present the greatest risk. The issue of non-ductile concrete buildings is further complicated by the visual similarity of these structures to some steel frame and most post-1976 reinforced concrete frame buildings.

Continue to move forward despite information gaps. In a perfect world, policy making would not proceed until after experts agreed on definitions and risk, and the buildings were counted, the presence of risk requires government intervention. As was demonstrated by the experience of the City of Los Angeles in the adoption and implementation of the URM ordinance, the length of the policy process, especially in the absence of a "policy window" should allow the time to figure these items out. It is even possible, that without a proposed policy as a catalyst, progress would not be made. At the very least, the information needed is likely to be ready by the time the City Council would adopt a proposed ordinance.

Most importantly, we urge policy makers to act before for a major earthquake occurs. To save lives and prevent loss, the policy process should begin as soon as possible.

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ACRONYMS AND ABBREVIATIONS

ATC	Applied Technology Council
CA	California
CBA	Cost-Benefit Analysis
CDF	Cumulative Distribution Function
EERI	Earthquake Engineering Research Institute
EPEDAT	Earthquake Post Damage Assessment Tool
EQ	Earthquake
FEMA	Federal Emergency Management Agency
L.A.	Los Angeles
LEED	Leadership in Energy and Environmental Deisgn
M	Magnitude
NDCB	Non-ductile Concrete Building
NDCS	Non-ductile Concrete Structure
PEER	Pacific Earthquake Engineering Research (Center)
SB	State Bill
SCEC	Southern California Earthquake Center
U.S.	United States
UBC	Uniform Building Code
URM	Unreinforced Masonry
USC	University of Southern California
USGS	United States Geological Survey

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APPENDIX A. NUMBER OF NON-DUCTILE CONCRETE BUILDINGS IN THE CITY

There is not a current tally of these buildings in the city, and no single source of data had all of the information needed for input into the model. Therefore, the project relies on several sources of data. It is expected that the number buildings and their degree of vulnerability will be refined over time; the cost-benefit simulation is designed to be responsive to this issue. The data sources and methodology for counting the number of buildings are described in detail below.

A.1 Data Sources

Three data sources were used, a verbal estimate provided by the Los Angeles Department of Building and Safety, data from The Early Post-Earthquake Damage Assessment Tool (EPEDAT) and the report *ATC 13 Earthquake Damage Evaluation Data for California*. The Los Angeles Department of Building and Safety estimates there are between 2000 and 3000 non-ductile concrete buildings within the City of Los Angeles.[1] While this source is extremely useful, such aggregate numbers do not indicate a specific building's location, year of build, structure size and shape, structural vulnerability, or social function (e.g. retail, residential, education, etc.). A number of buildings are excluded, including government owned buildings and those serving education, health, and other critical services such as transportation and utilities as they are subject to other legislation. Only privately owned buildings are counted in this project.

Data was also obtained from EPEDAT, which identifies the precise location of pre-1976 buildings within the City of Los Angeles.[2] This data set suggests there are around 500 such buildings, and hence we set this as our lowest estimation point for the overall model. A third data source and estimation procedure was used to both triangulate and increase the sensitivity of the calculations.

The third data source was the 1985 report *ATC 13*. The data in this report is split by building characteristics; year of build (pre-1950, 1950-1970, 1970-1985) and building height (low rise [1-3 stories], medium rise [4-7 stories], and high rise [8 or more stories]). The rest of this appendix describes the process for estimating building numbers on the basis of *ATC 13*. This process yielded estimates of between 1000 and 5000, which is in the same region as the above figures.

A.2 Estimation of Building Distributions

Year of Build - To estimate the distribution of year of build, 2006 American Community Census data for housing characteristics were employed. The Census data suggests that 22 percent of those buildings constructed prior to 1985 were built before 1950, 39 percent were built between 1950 and 1970, and 39 percent between 1970 and 1985. This appears to be a reasonable assumption to apply to all building types because residential structures represent the majority of buildings and floor space.

[1] Nick Delli Quadri, Los Angeles Department of Building and Safety, interviewed by the authors, April 13, 2008.
[2] EPEDAT, Early Post-Earthquake Damage Assessment Tool (EPEDAT) developed by EQE International, Inc.

Building Height - Building height distributions are more difficult to estimate due to a lack of data. It can be extrapolated that low rise buildings are by far the most common, with high rise buildings being relatively rare. Placeholders have been used in the model to represent building height.

Social Function – There were several sources of data available for this estimation. The first uses Caltrans data for square feet per employee by social function and multiplies by the numbers employed to estimate the total floor space for all buildings by social function. Employment figures are employed for industry while other units, such as occupants per building are used for functions such as housing. 2007 employment figures for Los Angeles County were acquired from the Labor Market Information Division of the California State Employment Development Department.[3] This data was subsequently adjusted to the City of Los Angeles level by calculating the proportion of County employment within the City (40 percent) and extrapolating across all industries. This provides an estimate total of 1,300 million square feet of privately owned floor space within the City of Los Angeles, of which 420 million square feet is non-residential. It is important to note that some social function areas, such as parking garages, were omitted due to insufficient data. As a reference point, another available data point estimates the total floor space of the Central City as 78 million square feet, which is 4 percent of the City of Los Angeles' floor space, which seems reasonable relatively.[4]

Multiplying these figures by the distributions for non-ductile concrete structures included in *ATC 13* provides an estimate of the non-ductile concrete structure floor space by each social function. Dividing these figures by the average building floor space (14,300 square feet per building for the pacific region of the U.S.) produces the numbers of buildings.[5] A final step is to subtract from the estimation the number of buildings built since 1985. Again using Census data for the housing stock year of build, it appears that there has been a 14 percent increase in residential buildings since 1985. This ignores that some buildings have been demolished since 1985. [6]

[3] State of California, Employment Development Department, Labor Market Information Division http://www.labormarketinfo.edd.ca.gov/cgi/databrowsing/?PageID=4&SubID=166 (accessed on March 13, 2008).
[4] Los Angeles Fashion District BID, *Economic Contributions of the Los Angeles Fashion District: Beyond the Trends 2006,* http://lafashion.veplan.net/custom/11/1107/misc/LAFA_EconContributions2006.pdf (accessed on March 13, 2008).
[5] Energy Information Administration, 2003
[6] Los Angeles Department of City Planning Demographics Research Unit website, http://cityplanning.lacity.org/dru/HomeDRU.cfm (accessed March 15, 2008).

APPENDIX B. SEISMIC LEGISLATION HISTORY

Seismic safety policy affecting the City of Los Angeles has a history spanning the 20th Century and beyond. This history provides some important lessons. It is clear that policies have often been adopted in reaction to major earthquakes. Substantial upgrades to building codes in California have largely been in response to the major earthquakes of 1933 (Long Beach), 1971 (San Fernando), 1984 (Mexico City), 1989 (Loma Prieta), and 1994 (Northridge). However, "trigger events" are only the beginning of a much longer process. Further related policies may be adopted in turn,[1] and the implementation of all policies is commonly a protracted and evolving process.[2]

B.1 Trigger Events and Initial Formulation, 1906 - 1971

The period between 1906 and 1971 witnessed the gradual emergence and then institutionalization of seismic safety as a policy issue area. Especially in the early years of earthquake legislation, policymaking was largely reactive rather than proactive. Major earthquakes opened the windows for policy makers to achieve the interventions advocated by the scientific community.

The initial impetus for policy making in California came from civil society. As earthquake historian Carl-Henry Geschwind describes, the Progressives of early 20th century California aimed to remove inefficiency from society, such as short-term decision-making that resulted in cheap yet unsafe building construction. The 1906 San Francisco Earthquake provided evidence for the progressive movement that government intervention was required to save lives and prevent economic loss. In response, prominent geologists formed the Seismological Society of America.[3] This organization aimed to influence public policy by providing objective analyses of earthquake risk through scientific evidence from a burgeoning field. This process eventually created what Geschwind refers to as "the Progressive alliance of science and the state in the promotion of seismic safety."

In 1925, Palo Alto became the first city to pass earthquake sensitive building code upgrades, following the Santa Barbara Earthquake.[4] However, it was not until after the 1933 Long Beach Earthquake that the California legislature and other cites would pass their own legislation. On March 10, 1933, the City of Long Beach experienced a magnitude 6.4 earthquake that left 120 dead and caused $41 billion in damages (around $750 billion in 2008 dollars).[5] At the time, the city's building code was essentially the same as the 1930 UBC, which was considered to hold

[1] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001).
[2] Alesch, D. and Petak, W.H. (2001) "Overcoming Obstacles to Implementing Earthquake Hazard Mitigation Policies: Stage 1 Report," Technical Report MCEER
[3] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001): 6.
[4] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 338
[5] Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986): 6.

buildings to strict standards. Despite these standards, 86 percent of URM buildings failed as a result of shaking.[6]

After the 1993 earthquake, City of Long Beach officials immediately began an investigation of the affects of the earthquake and the reasons for the extensive loss of life and property.[7] The City Council took quick action; Long Beach Building Inspector (and Seismological Society of America member) C.D. Wailes Jr, was able get seismic safety laws into the City of Long Beach's building code within 10 days the quake.[8] Exactly 30 days after the earthquake, the State of California adopted the Field Act, requiring that all public school building plans be approved and their construction supervised.[9] Within two months, the State legislature passed the Riley Act requiring all buildings built after May 23, 1933 to be constructed to far more rigorous standards.[10] Seven months following the Long Beach quake, the City of Los Angeles adopted earthquake-resistant measures for construction of new buildings.[11] Similar ordinances in Beverly Hills, Santa Monica, and Pasadena effectively ended the new construction of unreinforced masonry buildings in those municipalities.[12]

Outside of California, in March of 1964 Prince William Sound, Alaska experienced a 9.2 M earthquake that took 128 lives and caused approximately $311 million in property loss.[13] This quake served as a trigger for action by both the State of California and federal government, though federal legislation would not be passed until the late 1970's. However, earthquake safety promoters had moved into government institutions, such as those created by the California legislature's Joint Committee on Seismic Safety (the state agency to promote seismic safety, established 1969).

Little else changed regarding state earthquake standards until after 1971 when the San Fernando (also referred to as the Sylmar) Earthquake struck Southern California's San Fernando Valley. The magnitude 6.6 earthquake killed 60 persons, injured 2,400 persons, and left $500 million in property damage.[14] The damage was similar to the damage from the Long Beach Earthquake; half of the pre-1934 buildings had moderate to major damage.

In the two years following the San Fernando Earthquake, more seismically related legislation was passed in California than ever before. The damage from the quake confirmed once more the dangers of URM buildings to the City of Long Beach, and the city adopted the "Earthquake Hazard Regulations for Rehabilitation of Existing Structures within the City" in 1971. However,

[6] ibid: 6
[7] ibid: 6
[8] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001): 112
[9] ibid: 6
[10] ibid: 9
[11] Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986): 9
[12] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 338
[13] USGS. (No Date). Historic Earthquakes. Prince William Sound.
http://earthquake.usgs.gov/regional/states/events/1964_03_28.php accessed January 9, 2008
[14] USGS (No Date). Historic Earthquakes. San Fernando.
http://earthquake.usgs.gov/regional/states/events/1971_02_09.php accessed January 9, 2008

the presence of seismic experts in government appeared to have some effect. Notability, the head Building and Safety official for the City of Los Angeles refused to submit building code revisions to the city council in the month after the 1971 San Fernando Earthquake because he wanted to steer clear of "panic legislation."[15]

B.2 The Golden Age of Earthquake Policy, 1972-1986

Between 1972 and the mid-1980s, some of the most far-reaching policies were adopted across the region and the nation. The State of California adopted the Alquist–Priolo Earthquake Fault Zoning Act in 1972, preventing the construction of buildings used for human occupancy on the surface trace of active faults.[16] Cities such as Los Angeles, with the funds and expertise to develop codes, continued to push policy forward while other cities adapted and altered their building codes.[17] Such developments occurred alongside those of the UBC, which was updated every three years on the advice of the Structural Engineers Association of California.

Most relevant to this project were the steady advances in the City of Los Angeles building codes, which ensured that most new buildings were designed to withstand major earthquakes. Specifically, ductility requirements were added to new concrete structures in 1973 and then 1976, meaning that post-1976 concrete buildings are built to flex during high magnitude earthquakes. This period also highlights the movement away from reactive policy making. Major earthquakes continued to serve as triggering events. Yet because of further related policies being adopted, and the protracted and evolving implementation process, the impetus for any given policy became less clear. [18,19]

Between 1973 and 1977 came an array of various ordinances regarding URM buildings. In 1973, Councilmember Thomas Bradley of Los Angeles requested a feasibility study be done on the adoption of a building rehabilitation program for seismic safety. In 1974, the City Attorney drafted an ordinance requiring all existing motion picture theatres be brought up to code. (From the initial introduction of seismic legislation to the ultimate passage in 1981, the City of Los Angeles faced significant opposition from the Association of Motion Pictures and Television Producers, Inc., the California Society of Theatre Historians, the chamber of commerce, businesses, property owner, and other stakeholders.[20]) It took the City of Los Angeles nine years of negotiating to adopt an all-buildings ordinance to mitigate the earthquake hazards posed by URM buildings.[21] The ordinance was finally passed in 1981, with the assistance of an

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[15] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 150
[16] State of California, Department of Conservation. (No Date A). California Geological Survey - Alquist-Priolo Earthquake Fault Zones. http://www.consrv.ca.gov/CGS/rghm/ap/Pages/index.aspx (accessed April 11, 2008).
[17] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001): 170.
[18] Carl-Henry Geschwind, *California Earthquakes: Science, Risk, and the Politics of Hazard Mitigation*. (Baltimore: Johns Hopkins Press, 2001).
[19] Alesch, D. and Petak, W.H. (2001) "Overcoming Obstacles to Implementing Earthquake Hazard Mitigation Policies: Stage 1 Report," Technical Report MCEER (Multidisciplinary Center for Earthquake Engineering Research).
[20] Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986): 58.
[21] ibid, 79.

environmental impact report and an adjustment to the proposal to lessen the financial and social impacts, including allowing owners the option of a dual time phased retrofit.[22]

During the years following the 1971 San Fernando Earthquake, the State of California continued to discuss what caused the collapse of several hospitals. In 1973 the legislature passed the Alfred E. Alquist Hospital Facilities Seismic Safety Act (Alquist Act) to assure that hospitals would be able function and provide emergency services to the public following a disaster. As a result hospitals had to conform to higher construction standards. In 1983, eleven years after its initial passage, the Alquist Act was significantly amended and ultimately required all hospital construction plans be reviewed by the State of California, Office of Statewide Health Planning and Development and the Division of the State Architect.[23]

At a national level, the United States Geological Survey (USGS) had submitted a proposal for a 10-year National Earthquake Hazards Reduction Act after the 1964 Prince William Sound Earthquake. However it was not until 1977 that the *National Earthquake Hazards Reduction (NEHR) Act* was passed. NEHR is the primary federal earthquake legislation responsible for the implementation of new earthquake technologies and modified building codes and infrastructure design standards to reduce the risk of life and property from future earthquakes.[24] A critical element of NEHR was to assist state and local governments in creating and adopting earthquake mitigation plans for preparedness, response, and recovery.

B.3 Fixing Existing Buildings, 1986 – Present

The period from the mid-1980s until present witnessed a slowing in the rate of seismic safety policy making when compared with the previous decades. However, significant policies continued to be passed. Particularly important for this project was the shift of policy toward dealing with existing building stock. The earlier advancements in new-build policy had achieved substantial reductions in earthquake risk, yet the problem of older vulnerable buildings remained, leading numerous retrofitting policies to be adopted with mixed successes.

The State of California subsequently created the *California Earthquake Hazards Reduction Act of 1986* which was created to reduce seismic risks to life and property through improved design and construction methods, rehabilitation of hazardous buildings, and land use and redevelopment planning for the entire State of California.[25] Following the lead of earlier City of Long Beach and City of Los Angeles ordinances, the State of California recognized the dangers of URM buildings by passing SB 657 in 1986. The URM law required cities and counties in Seismic Zone 4 to identify and inventory certain older and potentially hazardous buildings by 1990.[26] This policy has been largely successful, yet involved a protracted implementation process that

[22] ibid, 72.
[23] State of California, Department of Conservation, *California Geological Survey - Alquist-Priolo Earthquake Fault Zones*, http://www.conservation.ca.gov/cgs/rghm/ap/Pages/chp_7_5.aspx (accessed April 7, 2008).
[24] National Earthquake Hazards Reduction Program. *About Us: History and Background*, http://www.nehrp.gov/about/ (accessed November 8, 2007).
[25] Robert S. Yeats, *Living With Earthquakes In California: A Survivor's Guide*, (OSU Press, 2001): 335
[26] Raymond J. Burby & Peter, May, *Making Governments Plan: State Experiments in Managing Land Use*, (Johns Hopkins University Press, 1997): 36.

remains incomplete. Nonetheless, substantial reductions in earthquake risk were achieved across the region and the State.

The 1985 8.1 M Mexico City Earthquake, 1989 Loma Prieta Earthquake and 1994 Northridge Earthquakes encouraged a sense of urgency to pass additional seismic retrofitting legislation. In late 1994, following the Northridge Earthquake, the state signed into law Senate Bill 1953, which amended and furthered the Alquist Act. SB 1953 has placed stringent regulations on hospitals. Hospitals may implement these changes in three phases, but ultimately by 2030 all hospitals must show they can be operational following a major disaster. The first phase of this law was intended to be completed by 2008, however this year the state passed SB 1801, which granted hospitals a five year extension to complete the first phase. This policy has been seen by many as an implementation failure. Many hospitals are facing obstacles due to the extremely high retrofit costs, and the State was forced to amend the legislation to provide timeframe extensions. California has also adopted several Health and Safety Codes granting cities and counties powers which include: the ability to identify and assess hazardous buildings; establish a building placard program in the most at-risk fault zones; and, implement supplementary risk reduction legislation.[27]

The City of Los Angeles passed an ordinance requiring the retrofitting of “tilt-up” wall buildings in 1994, only months after the Northridge Earthquake. Two years later, in 1996 the city enacted voluntary guidelines for the retrofitting of various types of buildings, including non-ductile concrete buildings.[28]

Concerns over seismic safety developed over a century ago, and the resulting policies have led incrementally to safer buildings. With each addition, such as the provisions made in 1992 with the URM law requiring the posting of placards on URM buildings at risk of failure during an earthquake (See Appendix for California Code 8875), important lessons have been learnt.[29] Seismic safety policy making was often triggered by major earthquakes, and, particularly during the first half of the 20th century, the opening of policy windows was an important part of the process. However, the protracted nature of earthquake policy formulation and implementation has caused the triggering events to become less distinguishable.

[27] City of Los Angeles, Municipal Code, http://www.amlegal.com/los_angeles_ca/ (accessed February 12, 2008).
[28] City of Los Angeles, California. (No Date). LAMC, Chapter IX, Section 95. (accessed on November 11, 2007), from http://www.amlegal.com/los_angeles_ca/
[29] CSSC, *Findings and Recommendations from the San Simeon Earthquake of December 22, 2003*, No. 04-02, (2004): 6.

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APPENDIX C. METHODOLOGICAL TECHNICAL APPENDIX

The methodology for the project uses both qualitative and quantitative elements to produce the results noted in the report. This technical appendix describes the steps taken to construct, and generate results from, the cost-benefit analysis model and the business owner decision-making sub-model. Although the decision-making model exists within the cost-benefit model, the complete cost-benefit model is presented first.

C.1 Conducting the Cost-Benefit Analysis

This section describes the steps taken to construct and calculate the cost-benefit analysis model. Cost-benefit analysis is a commonly used policy analysis tool. The essential function is to weigh the monetized social costs and benefits of policy outcomes as they deviate from the status quo. Cost-benefit analysis is based upon the utilitarian principle of the greatest good for the greatest number. Specifically, it builds from the Kaldor-Hicks principle, which states that if anyone is worse off as a result of a policy change, the winners can, in theory at least, compensate the losers.[1] A policy is deemed desirable if it provides greater overall benefits than overall costs. This process allows a comparison of the policy options' societal impacts by particular criteria. In this case, the criteria are the avoided economic and human (injury, trauma, and death) losses which the policy options would achieve. This enables an evaluation of the decision facing policy makers which is both quantitative and qualitative in nature.

First a generic model is described by mapping the criteria-based outcomes from all instances of variability within the policy options. The key costs and benefits are then identified and the process of calculating these factors is presented. Finally, a discussion of our data collection processes is presented.

C.1.2 Generic Model for Analysis

The first step of the process is to construct a generic model to describe the outcomes of the policy options. To do this, a "mapping" of all the possible outcomes from each policy option is necessary. This process is presented in this section.

As described above, the policy options fall under three broad areas: do nothing (retain status quo); impose a retrofit mandate for non-ductile concrete buildings; or, introduce a placard scheme which aims to influence building owners to retrofit. Ideally, the model should include variability within and between policy options. As described in the policy options section above, each policy has variability in certain areas. For example, placards could be voluntary or mandated and could vary greatly in terms of design, visibility, and the party which pays for the placard. The purpose here is to see how policy variability impacts the chosen criteria. Therefore, to simplify the process, the model is structured to compare "baseline" policy options which can then be altered, to capture the finer variability within the policy options.

[1] John R Hicks, "The Foundations of Welfare Economics." *Economic Journal,* 49 (1939): 696.
Nicholas Kaldor "Welfare propositions of economics and interpersonal comparisons of utility," *Economic Journal*, 49 (1939): 549–552.

C.1.2.1 State of Nature

The state of nature, or status quo, is when no changes are made to City of Los Angeles policy. If an earthquake of considerable magnitude were to occur without policy intervention, there would be substantial economic losses. These costs would consist of replacement costs, business interruption, debris removal, and potential lawsuits resulting from not retrofitting. The economic benefit would include avoidance of retrofit costs and other costs associated with retrofitting, such as administrative costs for inspections and permits, the loss of rental income, etc. The human impact would also be significant. The cost would be loss of life, injury, and trauma. There would be no human benefit.

C.1.2.2 Mandated "Life Safety" Retrofit of NDCS

The mandatory retrofit of a non-ductile concrete building would have greater benefits compared to the status quo due to the increased economic and human benefits of: shortened business interruption, less required repair to structures, decreased impact on employees, fewer individuals injured and more lives saved. The economic cost following an earthquake would continue to include repair costs and business interruption costs, however these costs would all be less compared to status quo economic costs, as non-ductile concrete buildings would be retrofitted and have a smaller economic impact. The human cost will include trauma, and may perhaps still include injuries and lives lost.

C.1.2.3 Placard Systems

At the highest level, the posting of placards can be voluntary or mandated. Additionally, the content of the placards could range from simple letter grades for all buildings of this type (such as is done with restaurants in Los Angeles County), to positive placards (similar to a LEED certification placard found on many buildings which are environmentally responsible) to semi-detailed explanations posted only on buildings which might be unsafe (as is generally done for URM structures). For the purposes of modeling, two variants of placards were selected: 1) Placards for all buildings within the scope of buildings with positive and negative seismic safety information; and, 2) Placards which contain only negative seismic safety information, such as those used under the Alquist-Priolo Earthquake Fault Zoning Act: State of California Government Code Section 8875.8 for unreinforced masonry buildings.[2]

C.1.3 Simplified Baseline Model

From this more precise outcome mapping process, a simplified baseline model is abstracted. Inevitably, subtleties are omitted from the model, yet this action allows for more manageable calculations and addresses a lack of data points in certain areas. The model essentially compares the policy impacts against the state of nature for each criterion. For example, retrofitting all vulnerable non-ductile concrete buildings would remove the risk of death during an earthquake. If an earthquake were to occur after the retrofit took place, the policy benefits could be estimated in terms of the number of lives which would have occurred without the retrofit. The model does not assume that the policy's impacts will be completed before the earthquake. As shown in Table C-1, benefits and costs are separated for ease of calculation and analysis.

[2] Official California Legislation Information Website. California Health and Safety Code http://www.leginfo.ca.gov/cgibin/waisgate?WAISdocID=48509422822+0+0+0&WAISaction=retrieve (accessed November 7, 2007)

Table C-1. Benefits and Costs

	Benefits	Costs
	Reduced losses which otherwise would have been caused by an earthquake.	Cost to society of implementing the policy.
Economic	• Reduced cost of replacement • Reduced business interruption	• Administrative costs • Retrofit costs • Cost of displaced occupants
Human Safety	• Injuries avoided • Deaths avoided • Other effects (such as trauma) avoided	• None

C.2 Estimating Key Costs and Benefits

The estimations of the key costs and benefits, as identified above, are based on a variety of data sources and expert interviews. One factor that influences all cost estimations is the number of non-ductile concrete buildings within the city. The process for estimating the number of these buildings was presented in Appendix A. All costs below are adjusted to 2008 prices using inflation rates specific to Los Angeles and the particular area studied, which for the most part is housing from the U.S. Bureau of Labor Statistics. Also, where necessary, triangulation of data sets is undertaken, with the most reliable data employed in the calculations.

C.2.1 Costs

The main costs for the model are the costs to property owners for retrofitting, and the administrative costs to the City of Los Angeles Department of Building and Safety.

C.2.1.1 Retrofit Cost

To calculate the retrofit cost to property owners, the total number of hazardous non-ductile concrete buildings in the City of Los Angeles (as estimated above) is distributed over the years following the policy introduction. This takes into consideration the reality that, first, not all non-ductile concrete buildings would be retrofitted, and second, those retrofits would not all occur in year one, but would be distributed across a number of years. For the placard policy option, it is assumed that placards will cause property owners to retrofit at 20 percent of the mandate rate. This is an arbitrary figure which can be varied easily within the model, and which is probably overestimated given our discussion of the decision model below. The second consideration allows for appropriate discounting of future retrofit costs to take place. For a baseline, it is assumed that retrofits are evenly distributed across a ten year span. This figure is then multiplied by the cost of retrofit per building, the distribution of which is based upon appropriate areas found in FEMA data for seismic retrofits.[3] The data for retrofit costs is provided in the following tables.

[3] FEMA, *Typical Costs for Seismic Rehabilitation of Existing Buildings,*" (FEMA 156, 1994).

Table C-2. FEMA Seismic Retrofit Data; All Buildings

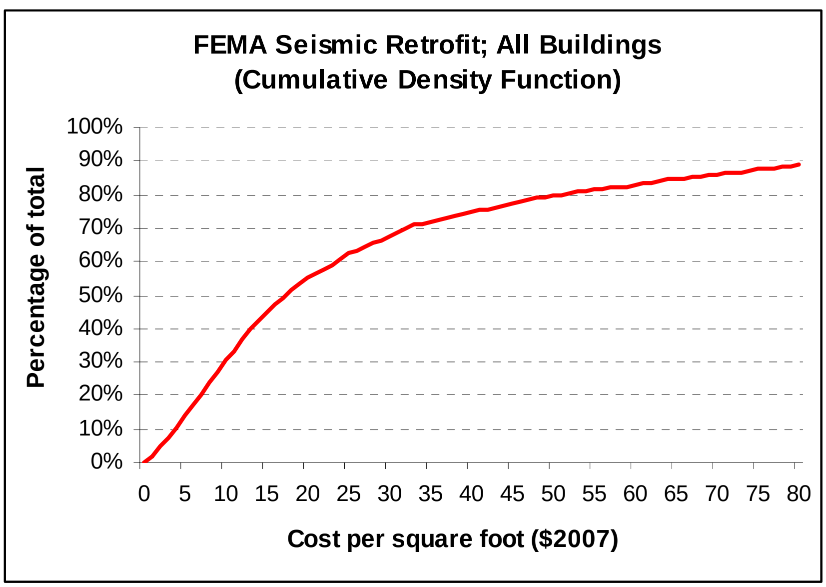
Count	Cost per sq ft ($2007)	Performance Objective
61	$15.13	**Risk reduction** - rehabilitating parts or portions of a structure without considering the entire structure for life-safety or greater performance.
987	$34.04	**Life-safety** - allows for irreparable damage as long as life is not jeopardized and ingress or egress routes are not blocked.
612	$36.85	**Damage control** - protect some feature or function of the building beyond life-safety, such as protecting building contents or preventing the release of toxic materials.
317	$52.72	**Immediate occupancy** - minimal post-earthquake damage and disruption with some nonstructural repairs and cleanup.

Authors' calculation, based on data from *FEMA 156, Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings,* September 1995.

Table C-3. All Buildings, median and percentile costs

CDF	Cost per sq ft ($2007)
25%	$9
Median	$17
75%	$41

Authors' calculation, based on data from *FEMA 156, Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings,* September 1995.

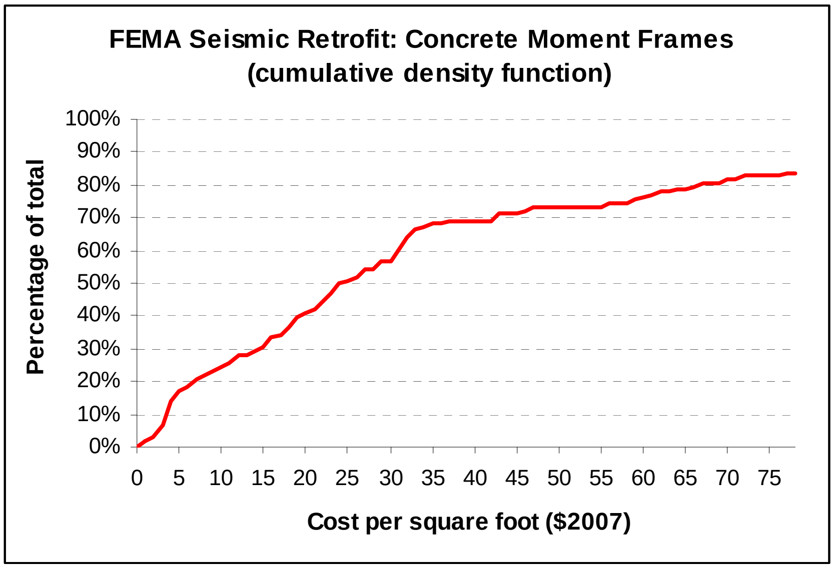


Authors' calculation, based on data from *FEMA 156, Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings*, September 1995.

Table C-4. FEMA Seismic Retrofit Data; Concrete Moment Frames

Count	Cost per sq ft ($2007)	Performance Objective
3	$1.85	**Risk reduction** - rehabilitating parts or portions of a structure without considering the entire structure for life-safety or greater performance.
81	$41.42	**Life-safety** - allows for irreparable damage as long as life is not jeopardized and ingress or egress routes are not blocked.
27	$47.05	**Damage control** - protect some feature or function of the building beyond life-safety, such as protecting building contents or preventing the release of toxic materials.
12	$48.23	**Immediate occupancy** - minimal post-earthquake damage and disruption with some nonstructural repairs and cleanup.

Authors' calculation, based on data from *FEMA 156, Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings*, September 1995.



Authors' calculation, based on data from *FEMA 156, Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings*, September 1995.

Table C-5. All Buildings, median and percentile costs

CDF	Cost per sq ft ($2007)
25%	$11
Median	$24
75%	$29

Authors' calculation, based on data from *FEMA 156, Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings,* September 1995.

C.2.1.2 Administrative Cost

The administrative costs vary considerably depending, among other things, on whether the policy adopted is a mandate retrofit or a placard program. Both policy options' administrative costs rely on the number of hazardous non-ductile concrete buildings in the City of Los Angeles. For the mandate, this figure is then used along with the decision model below to identify the number of buildings the policy would cause to retrofit and when the retrofit occurs. For the baseline model, the same assumption as for the retrofit cost applies. Finally, the number of buildings multiplied by policy administrative costs provided in Alesch and Petak (1986) for the URM ordinance.

For placards, the non-ductile concrete building estimate is used to identify the numbers of structures the policy would cause to be placarded, and when the placard would be assigned. The baseline model assumes that all placards would be assigned in year one of the program. It also assumes that all placards will be posted, although this would require specific efforts by the Department of Building and Safety.

C.2.2 Calculating Benefits

The benefits of seismic retrofitting policies are the avoided costs of a future earthquake. Therefore, the first step requires earthquake modeling to generate the impact of a potential earthquake.

C.2.2.1 Earthquake Impact Modeling

Again, the number of non-ductile concrete buildings in the City of Los Angeles is required first. This figure is then split by building height (low rise, 1-3 stories; medium rise, 4-7 stories, and high rise, 8 or more stories) using distributions for the relevant building types from EPEDAT data.[4] It is then split by building social function, which describes the purpose of the building.[5] The resulting figures are then multiplied by data from earthquake impact scales, which converts the earthquake magnitude to the "central damage function" (the damage cost as percentage of total replacement cost; *ATC 13*).[6] This provides an estimate of the number of buildings affected by a given magnitude earthquake, by height and building social function, which is then divided by average square footage for each height group using EPEDAT data.[7]

C.2.2.2 Replacement Costs

To estimate the replacement costs, the results of the earthquake impact step are multiplied by the replacement costs per square foot and by social function provided in *ATC 13* and summed.[8] Finally, costs are assigned to a given year (year of earthquake), so that they may be appropriately discounted.

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[4] EPEDAT, Early Post-Earthquake Damage Assessment Tool (EPEDAT) developed by EQE International, Inc.
[5] ATC. *Earthquake Damage Evaluation Data for California* (ATC, 1985), and employment data by social function extrapolated from 2006 Census data for the County of Los Angeles, www.census.gov (accessed March 15, 2008).
[6] Applied Technology Council *Earthquake Damage Evaluation Data for California* (ATC, 1985).
[7] EPEDAT, Early Post-Earthquake Damage Assessment Tool (EPEDAT) developed by EQE International, Inc.
[8] Applied Technology Council *Earthquake Damage Evaluation Data for California* (ATC, 1985).

C.2.2.3 Business Interruption

To calculate the estimated number of occupants within a damaged building at 3pm and 3am, the results of the earthquake impact step are multiplied by the estimated numbers of occupants at 3pm and 3am, which are provided in *ATC 13* data.[9] Finally, after summing, the results are multiplied by an estimate of cost per number of occupants.[10]

C.2.2.4 Human Safety

To estimate the human impact of a given earthquake, the occupants per building estimates are multiplied by the human injury and death estimates from *ATC 13*.[11]

Table C-6. Administrative costs for URM ordinance

Task	Alternative		
City of Los Angeles	**Full Compliance**	**Wall Anchors and Full Compliance**	**Wall Anchors Only**
Field Survey Building	113	113	113
Draft Compliance Order	42	42	42
Est. File, type order, type, notarize, record and file certificate	28	28	28
Certified mail or hand deliver order	35	35	35
Log and file plans, make computer entry	42	28	28
Check plans, issue permits	692	173	173
Type completion letter or reminder notices		8	
Check plan, issue permits		2289	
Inspect completed construction		911	
Prepare termination of earthquake hazard report	85	85	85
TOTAL BUDGETARY COSTS	**1942**	**4181**	**945**

Source: Alesch and Petak (1986)

Table C-7. Distribution of floor space for pre-1976 concrete buildings

Low-Rise	Medium-Rise	High-Rise
2,763	61,815	243,014

Source: Author's calculations based on EPEDAT data.

[9] Applied Technology Council *Earthquake Damage Evaluation Data for California* (ATC, 1985).
[10] Quigley, J.M. "Earthquake! The Use of Economic, Engineering, and Statistical Information to Invest in Seismic Safety." *Japanese Journal of Regional Economics*, 3, 1998: 9-20.
[11] Applied Technology Council *Earthquake Damage Evaluation Data for California* (ATC, 1985).

**Table C-8. Earthquake impact conversion:
Modified Mercalli Intensity into Central Damage Factor**

Low Rise

Central Damage Factor	Modified Mercalli Intensity 6	7	8	9	10	11	12
0	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	45.7%	1.1%	37.5%	0.0%	0.0%	0.0%	0.0%
5	51.4%	97.9%	62.3%	2.5%	0.4%	0.0%	0.0%
20	0.0%	1.0%	0.2%	88.0%	44.6%	6.6%	0.5%
45	0.0%	0.0%	0.0%	9.5%	54.6%	78.8%	41.6%
80	0.0%	0.0%	0.0%	0.0%	0.4%	14.6%	57.9%
100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Medium-Rise

Central Damage Factor	Modified Mercalli Intensity 6	7	8	9	10	11	12
0	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	30.9%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
5	68.8%	96.9%	33.6%	1.9%	0.2%	0.0%	0.0%
20	0.0%	2.8%	65.7%	65.1%	30.8%	3.6%	0.5%
45	0.0%	0.0%	0.7%	33.0%	67.7%	70.0%	27.9%
80	0.0%	0.0%	0.0%	0.0%	1.3%	26.4%	71.2%
100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%

High-Rise

Central Damage Factor	Modified Mercalli Intensity 6	7	8	9	10	11	12
0	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5	27.0%	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%
5	72.9%	89.3%	32.2%	3.0%	0.0%	0.0%	0.0%
20	0.0%	8.5%	66.9%	68.1%	19.9%	3.9%	0.1%
45	0.0%	0.0%	0.9%	28.9%	74.2%	57.8%	12.4%
80	0.0%	0.0%	0.0%	0.0%	5.9%	38.3%	84.3%
100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.2%

Source: *ATC 13*

Table C-9. Human safety and death estimates resulting from Central Damage Factor

Central Damage Factor	Injured	Dead
0	0	0
0.5	0	0
5	1%	0
20	2%	0.25%
45	2%	0.25%
80	10%	1%
100	100%	20%

Source: *ATC 13*

Table C-10. Estimate % of Building floor space and number of occupants at 3pm and 3am by building social function

Building Social Function	Estimated % of Building Floor Space	Number of Occupants at 3pm	Number of Occupants at 3am
Residential	76.0%	1.2	3.1
Hotels	0.4%	0.6	2.5
Group Homes	n/a	2	3
Retail Trade	9.2%	10	0
Wholesale Trade	4.2%	1	0
Other Services	1.0%	4	0.1
Financial Activities	0.9%	4	0
Professional and Business Services	2.3%	4	0
Arts, Entertainment and Recreation	0.5%	6	0
Accommodation	0.3%	6	0
Full Service Restaurant	1.1%	6	0
Limited Service Eating Places	0.4%	6	0
Special Food Services	0.1%	6	0
Drinking Places	0	6	0
Parking	0	0.2	0
Textile Mills	0.3%	3	0.3
Apparel Manufacturing	1.1%	5	0.3
Food Manufacturing	1.2%	2.5	0.3
Chemical Manufacturing	0.6%	2.5	0.3
Printing	0.2%	3	0.3
Religion/Non-Profit	0.3%	65	0

Source: *ATC 13*

Table C-11. Replacement Cost ($2007)

Building Social Function	Low-Rise	Medium-Rise	High-Rise
Residential	107.98	140.37	129.57
Hotels	129.57	140.37	129.57
Group Homes	64.79	0.00	0.00
Retail Trade	151.17	140.37	129.57
Wholesale Trade	118.77	140.37	183.56
Other Services	86.38	118.77	0.00
Financial Activities	151.17	172.76	194.36
Professional and Business Services	172.76	172.76	194.36
Arts, Entertainment and Recreation	118.77	140.37	183.56
Accommodation	205.15	205.15	205.15
Full Service Restaurant	161.96	172.76	194.36
Limited Service Eating Places	161.96	172.76	194.36
Special Food Services	53.99	107.98	107.98
Drinking Places	97.18	129.57	0.00
Parking	118.77	140.37	183.56
Textile Mills	97.18	0.00	0.00
Apparel Manufacturing	97.18	0.00	0.00
Food Manufacturing	97.18	0.00	0.00
Chemical Manufacturing	97.18	0.00	0.00
Printing	97.18	0.00	0.00
Religion/Non-Profit	151.17	172.76	194.36

Source: *ATC 13*

C.2.3 Probability

The final step of the calculations is to adjust the model for risk. As future earthquakes are uncertain events, all potential future savings should be weighted by probabilities. As stated above, there is a 67 percent chance that a 6.7 magnitude earthquake will hit the Los Angeles region during the next 30 years. This data point is taken from a recent USGS report, which estimates the likelihood of different magnitude earthquakes for different areas of California using state of the art computer simulations.[12] Probabilities for other magnitudes of earthquake in the Los Angeles region (7, 7.5, and 8) are initially estimated by extrapolating USGS data for other areas, and will be improved after consulting with our clients at the Southern California Earthquake Center.

To calculate the probability of the earthquake occurring in any given year, USGS provides a simplified formula, which is presented in the following table.[13]

[12] Edward H. Field, et al, *The Uniform California Earthquake Rupture Forecast, Version 2* (United States Geological Survey, 2008).
[13] USGS *About Annual Probability of Exceedance*, USGS website: http://earthquake.usgs.gov/research/hazmaps/haz101/faq/parm09.php (accessed April 4, 2008).

Table C-12. Probability Estimation

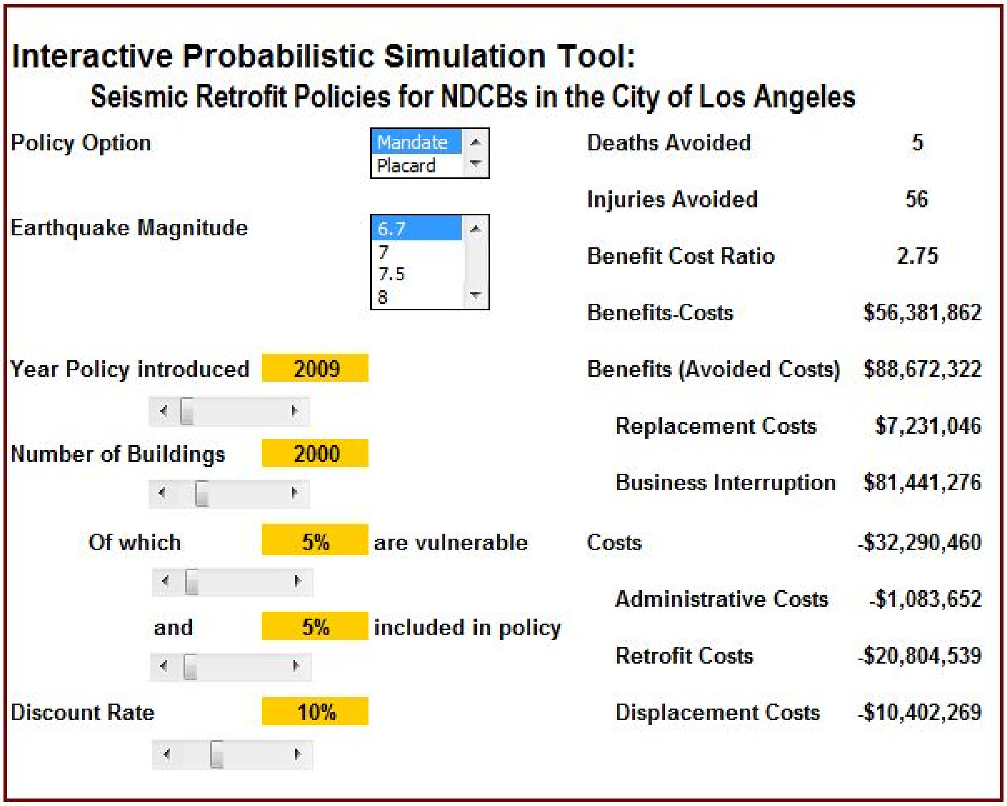
P(A) = About Annual Probability of Exceedance
N = Number of Years in Time Frame
r = N Year Probability of Exceedance
$P(A) = r(1+0.5r) / N$

For example, for 67 percent over 30 years, the annual probability of an earthquake is 0.67(1+0.5*0.67)/30 = 2.98% chance of an earthquake in any given year.

The annual probability of exceedance is applied to all of the cost values within the model. These risk-weighted values are then summed to calculate the expected value outcomes, both economic and human safety.

A screenshot of the front end of the simulation is shown below, in Figure C-3.

Figure C-3. Simulation Tool in Microsoft Excel



C.3 Decision Modeling for Building Owners and Users

In assessing the impact of the policy alternatives, it is necessary to understand the reactions of both building owners and users. Building owners and users alike play a particularly important role in the policy process, making numerous and interactive decisions which mold the implementation of the policy into workable outcomes. Modeling these complex decisions is as much an art as a science, requiring various simplifying assumptions. This section presents the authors' estimation of a generic decision model for all non-ductile concrete building owners, along with explanations of the theory behind the decision model and how it affects the broader policy impact modeling.

❖ It is important to note that this model is based upon a combination of a literature review and logical reasoning, and is not tested by empirical research. This modeling is based on the ideas presented in Von Winterfeldt et al (2000).[1]

C.3.1 Generic Model for Building Owners

The critical decision for non-ductile concrete building owners is what action to take regarding the earthquake hazard. Currently, in the "status quo," the building owner has three basic available options: do nothing, take out insurance, and retrofit. These second two options may be conducted in tandem. Both also entail certain expenditure of funds, and an uncertain reduction of economic and human safety risks. Such activities are influenced to varying degrees by the value of the property (building and land), the revenue generating capacity of the property, the funds available to the building owner, and the building owner's risk perception.

The expected outcome of decision alternative d_x, whether the property owner retrofits or otherwise, is based upon a cost-benefit calculation of the retrofit given available resources, current insurance coverage, property value, revenue stream, and risk perception:

$$D_x\ 0,1 = (s_1 - s_2) \,\big|\, (s_3, s_4, s_5, s_6),(s_7)$$

where:

s_1 = Cost of d_1 or d_2 to the property owner
s_2 = Risk reduction from retrofit activity
s_3 = Cost of insurance
s_4 = Risk reduction from insurance
s_5 = Property market value
s_6 = Property revenue stream
s_7 = Earthquake risk (weighted for risk perception)

The policy alternatives both influence this decision model in particular ways. The placard option will offer the same basic options of do nothing, take out insurance, and retrofit. Insurance rates

[1] Detlof Von Winterfeldt, Nels Roselund, and Alicia Kitsuse, *Framing Earthquake Retrofitting Decisions: The Case of Hillside Homes in Los Angeles*, Pacific Earthquake Engineering Research Center, http://peer.berkeley.edu/publications/peer_reports/reports_2000/reports_2000.html (accessed March 15 2008).

will be affected by the increased information available to insurance companies, and the revenue generating capacity of the property will be affected by the changed risk perceptions of building users. On the other hand, the seismic retrofit mandate option will leave the building owner with one of three options: retrofit, leave the building vacant, or demolish.

C.3.2 Outcomes

In assessing the outcomes of the policy, it is necessary to estimate the likelihood that the above decision options will be made. To do this accurately would require a great deal of empirical data about the various aspects of the model. However, due in part to the use of aggregate data elsewhere in the policy impact modeling, it is neither possible nor practical to attain precise figures on the variables included within the model. Instead, the model focuses on estimates of the critical element; risk perception, using theory and empirical research from the academic literature.

Economic Factors	Psychological Factors
Retrofit cost (and risk reduction)	Risk perception
Insurance cost (and risk reduction)	Bounded rationality
Property value	
Property revenue generating capability	
Available funds	

C.3.3 Risk Perception

There is a developed academic literature of risk perception, which includes the role it plays in earthquake hazard mitigation decision making. Risk perception studies show that when confronted with a trade-off between emotion and calculation, people tend to choose the former. This helps to explain why people make choices which are seemingly “risk averse,” or at the other end of the spectrum, high-risk gambles. It also helps explain why people prioritize the fear of crime or terrorism, over the statistically more likely events of an accident on the road or in the home. Part of this prioritization is the result of the feeling of control, and the desire to seek control over one’s fears. However, the role of public information sources, particularly the media, is substantial. Communal media events such as terrorist attacks, violent crimes, natural hazards, or economic shocks serve to heighten the public awareness of particular issues, in turn opening windows to policy making.[2]

The public’s risk perception regarding earthquake hazards appears to follow these rules. Various surveys show that the public is more concerned with phenomena such as air pollution, traffic congestion, climate, noise, and crime than it is with earthquake hazards.[3] Sims and Bauman (1972) find that “internal control” is statistically related to fatalism about earthquakes. This lack of concern contributes to a lack of policies designed to reduce risk. Case studies show that

[2] William J. Burns, *Risk Perception: A Review* USC CREATE Center for Risk and Economic Analysis of Terrorism Events. http://www.usc.edu/dept/create/assets/003/54570.pdf (accessed March 15, 2008).
[3] Including Jackson, 1977, 1981; Jackson & Mukerjee, 1974; Kiecolt & and Nigy, 1982, as cited in Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986).

seismic safety has been a low priority among policy makers.[4] In his study in the wake of the 1981 City of Los Angeles URM ordinance, public administration scholar Bruce Clary found that URM building occupants were more concerned with "price inflation, violent crime, and automobile accidents" than earthquake hazards.[5] Despite a major earthquake since then, it is unlikely that this distribution will have changed much. Indeed, terrorism is likely to have taken another place above earthquake risk in the public's priority rankings.

When looking specifically at government hazard mitigation policies, Clary found that the public were most supportive of placards, with retrofit options gaining less favor. In a more specific study involving URM building owners, decision analysis scholars Detlof Von Winterfeldt and Richard S. John found through a "value tree analysis" process (which enables the researcher to systematically prioritize option preferences) that those more economically minded respondents preferred "forced demolition of all URM after 25 years," while a more flexible policy of "wall anchoring only" appeared to suit all preferences best.[6] In a later study, the same authors find that economic impacts were the primary concern of building owners in Los Angeles, specifically the disruptive effect on business and a lack of available funds for the retrofit. A further concern involved uncertainty over the city council policy making. Interestingly, building owners were opposed to both eliminating the policy, and to public financing of the policy. Instead, they favored the options of loan financing, tax incentives, and the relaxing of specific ordinance aspects. Building owners were also positive about policy implementation being withheld until funds were available, the binding of the city council to agreements to reduce uncertainty, and the adoption of a statewide policy to address the problems of competition between cities within the Los Angeles basin region.

The URM ordinance case provides further interesting data on the likely impacts of a future retrofit ordinance. Earthquake policy scholar Mary C. Comerio (1992) shows that 10 years after the Los Angeles ordinance was enacted, only 55 percent of residential URM buildings were complete, 13 percent were in progress, 12 percent had been demolished, and some 20 percent were yet to be completed. Although the vast majority of URM buildings eventually were retrofitted or replaced, the length of time taken highlights the endemic resistance to such policies. Also of interest, the average rent increase for tenants was between 14-26 percent, while some tenants were forced to vacate.[7]

C.3.4 Decision Model Conclusions

Risk perception studies, in general and specific to Los Angeles earthquake policies, suggest that any policy to increase non-ductile concrete building retrofits will be slow to yield results. Given that the current voluntary mandate scheme for these types of buildings is largely ineffective, it is difficult to imagine a placard program inducing much more action. Building owners and

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[4] Wyner & Mann, 1983, cited in Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986)..

[5] Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986).

[6] Detlof Von Winterfeldt & Richard S. John in Dan Alesch & William H. Petak, *The Politics and Economics of Earthquake Hazard Mitigation: Unreinforced Masonry Buildings in Southern California* (1986)..

[7] Mary C. Comerio, "Impacts of the Los Angeles retrofit ordinance on residential buildings," *Earthquake Spectra* 8 (February 1992): 79-94.

occupants alike may have their perception of risk changed, especially if the process in some way affects them emotionally. However, because the chance of an earthquake is small, non-emotional calculations are unlikely to encourage building owners to retrofit. Such businesses may become less profitable, but the loss in revenue is unlikely to cover the costs of retrofitting. A mandate would be more effective, but is likely to face resistance from building owners. Either the retrofit would be stalled, as has been the experience of the State Hospital retrofit bill, or the building would be vacated. Although this latter option reduces the risk to human life, this scenario creates economic inefficiencies and contributes to urban decay.